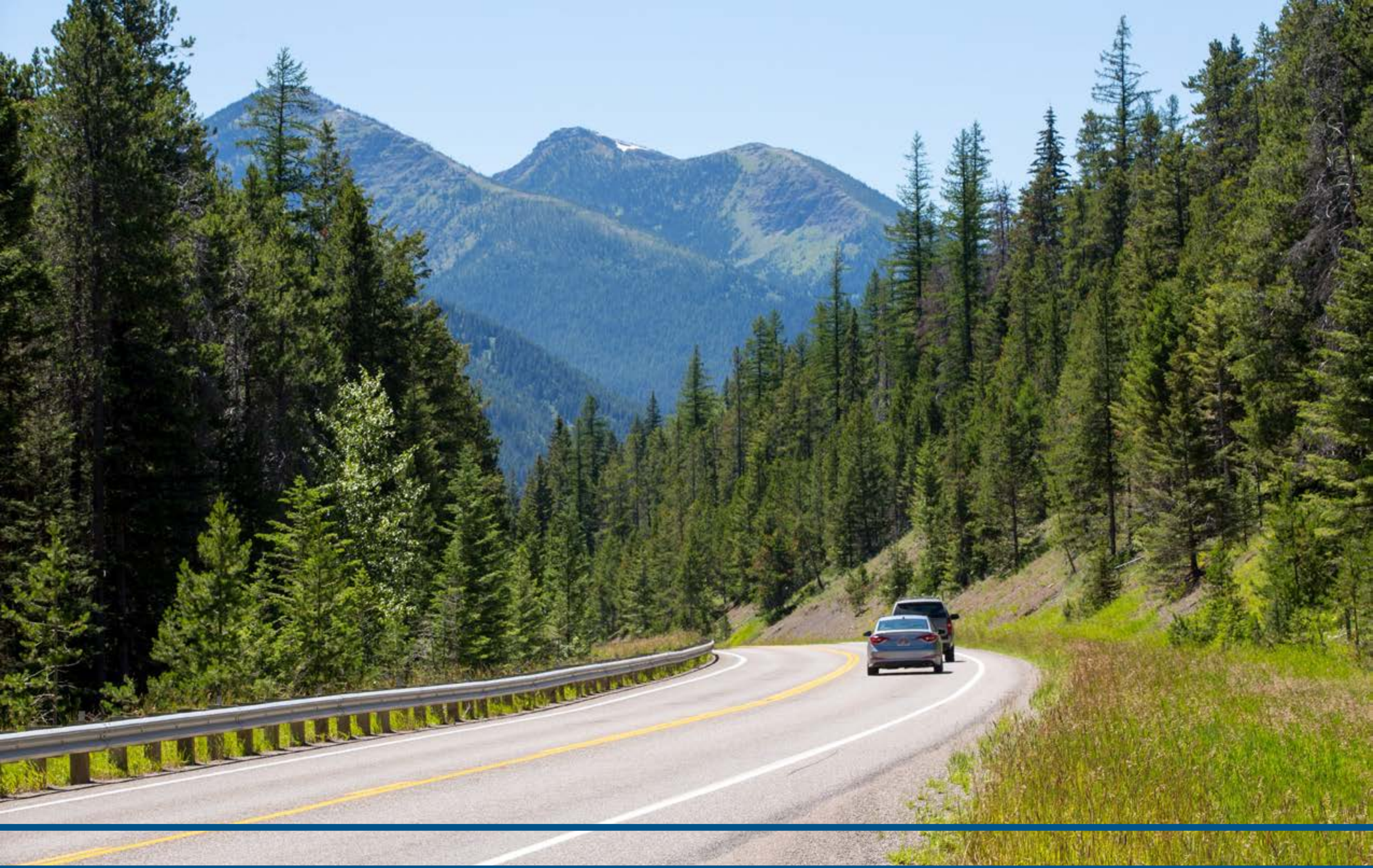

ROAD DESIGN MANUAL

September 2016

MONTANA MDT DEPARTMENT OF TRANSPORTATION

PREFACE

The Montana Department of Transportation (MDT) *Road Design Manual (RDM)* has been developed to provide uniform design practices for MDT and consultant personnel preparing contract plans, specifications and estimates for MDT projects. The design team should attempt to meet all criteria presented in the *RDM*. However, the *RDM* should not be considered a "standard" which must be met regardless of impacts.

The *RDM* presents most of the information typically required in the design of a roadway project; however, it is impossible to address every situation which the design team will encounter. Therefore, the design team must exercise sound engineering judgment on individual projects and, frequently, they must be innovative in their approach to roadway design. This may require, for example, additional research into the highway literature.

The *RDM* was developed by the MDT Road Design Section with assistance from the transportation engineering consulting firm of Kittelson & Associates, Inc. The RDM Review Committee consisted of:

Damian Krings, P.E. (Project Manager)	MDT Road Design Engineer
Paul Ferry, P.E.	MDT Highways Engineer (retired)
Benjamin Nunnallee, P.E.	MDT – Missoula Preconstruction
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Aaron Mason	MDT – Road Design
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The RDM Review Committee would like to thank the following contributors for their technical assistance in developing the manual:

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John Cornell, Jerry Sabol, Jeremy Terry, Louise Stoner, Josh Dold, Scott Gerken, Jim Dunbar, Rodney Payne – MDT Road Design
Dave Hedstrom and Annette Compton – MDT Hydraulics
Danielle Bolan and Darcy O'Dell – MDT Traffic

REVISION PROCESS

All revisions to the MDT *Road Design Manual (RDM)* will be submitted and reviewed according to the following process:

Revision and Review

1. Submit all requests for clarifications, errors, omissions, questions and proposed revisions to the Road Design Manual Committee using the Road Design Manual Comment Form.

2. The Road Design Manual Committee will review proposed changes during scheduled meetings.

3. The Road Design Manual Committee (see below) will coordinate with the appropriate Bureaus and District personnel to determine recommended revisions to the RDM. Final recommendations will be submitted and presented to the Highways Engineer for approval consideration.

4. Proposed revisions that violate MDT Policy cannot be implemented unless the affected Policy has been revised, replaced or rescinded. Policy changes require approval from the appropriate Division Administrators. The Road Design Manual Committee will meet with the Preconstruction Engineer and the appropriate Division Administrators to present and discuss RDM recommended revisions that would require a change of Policy prior to approval.

5. The Highways Engineer will issue a design memo describing each revision that has been approved. The electronic RDM errata/revision file will identify the RDM content affected by the revision and the supporting design memo.

6. All errata and approved revisions will be incorporated into the RDM for republishing every four years, at which time the replaced RDM, design memos, and errata/revisions file will be archived.

Road Design Manual Committee

The Road Design Manual Committee will consist of four to five members. The Road Design Engineer and the Highways Design Engineer will remain Committee core members. Two District and/or Helena Engineering Division personnel will be recruited to participate on the Committee for two year terms. The two year terms are to be staggered in a manner so that only one member is replaced in any given year. The Committee may invite a fifth member to participate on a minimum annual basis. The four members will make this decision based on agenda topics.

Review Committee responsibilities include:

1. Meeting on an annual basis, or as often as necessary, to review the proposed RDM changes.
2. Adequately reviewing and researching the proposed RDM changes.
3. Providing recommendations to approve or disapprove requested updates for the *RDM*,
4. Tracking all revisions to the *RDM* in chronological order

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Chapter 1

Road Design Guidelines and Procedures

1.1 INTRODUCTION

Chapter 1 introduces the Montana Department of Transportation (MDT) *Road Design Manual (RDM)* by describing the manual's purpose, scope, and primary definitions. This chapter presents the nationally recognized perspective of the project development process and introduces topics such as performance-based road design and multimodal design considerations. Chapter 1 includes an overview of MDT road design activities, process, and project coordination. This chapter sets the basis for the entire manual by outlining key concepts and providing a fundamental understanding of the design policies and procedures for executing a design project within MDT.

1.1.1 Purpose of the Manual

The *RDM* has been developed to provide uniform design practices for MDT design teams and consultant personnel preparing contract plans for projects involving MDT facilities. While the design team should use the guidance and criteria presented in the *RDM* to execute the design project, the *RDM* should not be considered a standard which must be met regardless of impacts.

Engineering judgment is the evaluation of available pertinent information and the application of appropriate principles for the purpose of making design decisions.

The *RDM* presents a majority of the information that is typically required throughout the course of a roadway design project. However, the design team must exercise engineering judgment when making decisions to execute a design approach that meets the desired outcomes of a project within the context of that project. This may require innovative design approaches, consulting with other departments and staff, and even additional research into highway literature to reflect the most recent best practices.

1.1.2 Scope of the Manual

The *RDM* outlines the design process, design team coordination, and design principles and approaches for various types of projects. Design controls and considerations are presented for horizontal alignment, vertical alignment, and cross sections for the range of roadway facility types. Design elements, such as drainage, roadside safety, and traffic control during construction are presented, with references to detailed plans and additional resources within MDT. The *RDM* presents design considerations for various modes of travel in both rural and urban design environments. Geometric design criteria that are referenced throughout the *RDM* are provided in the *MDT Geometric Design Standards (1).*

An overview of the process of preparing detailed plans, specifications and special provisions are provided within the manual, while actual example plans and specifications are provided in a separate document that is referenced and linked within the *RDM*. The *RDM* contains appendices that provide a comprehensive glossary of definitions for the terminology used throughout the chapters, as well as additional design calculation examples.

Information in this manual is cross-referenced between chapters to provide a clear understanding of the design process and coordination between disciplines.

While the *RDM* contains a large amount of detailed design information, this manual also provides links to other MDT manuals and resources that will be important to the design team throughout the project. The *RDM* was developed in coordination with various MDT bureaus and units to illustrate the interactive relationships among those bureaus and units. Information related to these topics is cross-referenced to provide the design team a clear understanding of the overall design process and close coordination with the multidisciplinary engineering project team. For example, the traffic engineering elements, in particular, will serve as important resources for the design team when projects include coordinating the geometric design of intersections, interchanges, and other traffic engineering elements.

All numerical values presented within the text and exhibits are presented in United States (U.S.) Customary Units.

1.1.3 Definitions

This section presents the specific qualifying words used throughout the *RDM* and provides definitions for overarching key terminology. Appendix A provides a comprehensive glossary of terminology for the entire *RDM* and cross references appropriate chapter content.

1.1.3.1 Qualifying Words

Many qualifying words are used throughout design projects and within the *RDM*. For consistency and uniformity in the application of various design criteria, the following definitions apply:

1. **Shall, require, will, must.** A mandatory condition. The design team is obligated to adhere to the criteria and applications presented in this context or to perform the evaluation indicated. For the application of geometric design criteria, the *RDM* limits the use of these words.
2. **Standard.** Indicating a design value which cannot be changed without formal documentation, such as a design exception. Therefore,

"standard" is not used in the *RDM* to apply to geometric design criteria, except for the design exception discussion in Chapter 2, Section 2.9.

3. **Criteria.** A term typically used to apply to design values, usually with no suggestion on the criticality of the design value. Because of its basically neutral implication, the *RDM* frequently uses "criteria" to refer to the design values presented.

4. **Should, recommend.** An advisory condition. The design team is strongly encouraged to follow the criteria and guidance presented in this context, unless there is reasonable justification not to do so.

5. **Guideline.** Indicating a design value which establishes an approximate threshold which should be met if considered practical.

6. **Target.** Selected criteria that the design team is striving to achieve. However, not meeting these criteria will typically not require a justification.

7. **Policy.** Indicating MDT practice which MDT generally expects the design team to follow, unless otherwise justified.

8. **May, could, can, suggest, consider.** A permissive condition. The design team is allowed to apply individual judgment and discretion to the criteria when presented in this context. The decision will be based on a case-by-case assessment.

9. **Desirable, preferred.** An indication that the design team should make every reasonable effort to meet the criteria and that they should only use a less desirable or less preferred design after due consideration of the desirable or preferred design.

10. **Ideal.** Indicating a condition that may not exist in reality or be achievable under practical constraints (e.g., traffic capacity under "ideal" conditions).

11. **Minimum, maximum, lower, upper, (limits).** Representative of generally accepted limits within the design community but not necessarily suggesting that these limits are inflexible.

12. **Practical, feasible, cost-effective, reasonable.** Advising the design team that the decision to apply the design criteria should be based on a subjective analysis of the anticipated benefits and costs associated with the impacts of the decision. No formal analysis (e.g., cost-effectiveness analysis) is intended, unless otherwise stated.

13. **Possible.** Indicating that which can be accomplished. Because of its rather restrictive implication, this word will not be used in the *RDM* for the application of geometric design criteria.

14. **Significant, major.** Indicating that the consequences from a given action are obvious to most observers and, in many cases, can be readily measured.

15. **Insignificant, minor.** Indicating that the consequences from a given action are relatively small and not an important factor in the decision-making for geometric design.

Additional information regarding design standards and design decisions is discussed in Chapter 2, Section 2.9.

16. **Typical.** Indicating a design practice that is most often used in application. However, this practice does not necessarily represent the "best" treatment at a given site.
17. **Acceptable.** Design criteria which do not meet desirable values, but yet is considered to be reasonable and safe for design purposes.

1.1.3.2 Key Terminology

While some chapters include key terminology as part of the introduction to the chapter, a comprehensive list of definitions and acronyms are provided in Appendix A. The definitions provided in Appendix A are cross-referenced with relevant chapter material to allow design teams to reference appropriate terms and design concepts throughout the *RDM.*

1.2 PROJECT DEVELOPMENT PROCESS

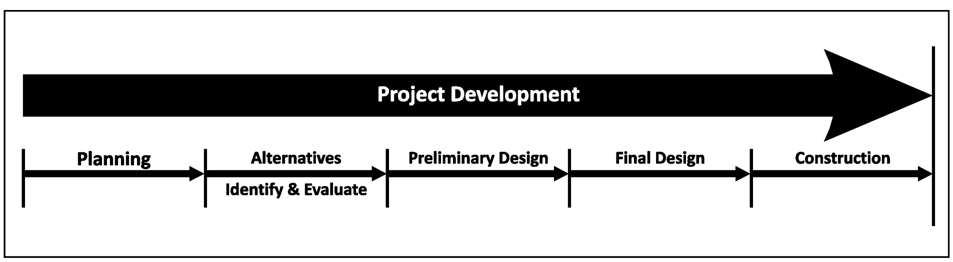
The project development process outlines the primary stages that occur within a transportation project. The following sections provide an overview of the project development process stages, an overview of performance-based road design and describe the MDT-specific activities and project development stages.

1.2.1 National Perspective

A clear understanding of each stage of the process and design team coordination can help align design decisions with the desired outcomes.

Exhibit 1-1 provides an overview of a representative project development process. Road design may have limited roles in the planning stage of project development and may become most relevant during the alternatives identification and evaluation stage and the preliminary design stage. A clear understanding of each stage of the process and design team coordination throughout the entire project can help align design decisions with the overall desired outcomes of the project. Descriptions for each stage of the project development process are provided below.

Exhibit 1-1 Representative Project Development Process ***(2)***



1.2.1.1 Planning

Planning often includes exercises such as problem identification and other similar steps to establish a connection between the project purpose, and the geometric concepts being considered. Planning studies could include limited geometric concepts on the general type or magnitude of project solutions to support programming *(2)*.

1.2.1.2 Alternatives Identification and Evaluation

The project needs identified in prior planning studies inform concept identification, development, and evaluation. At this stage, understanding and documenting the project context and intended outcomes are needed so potential solutions may be tailored to meet project needs within the opportunities and constraints of a given effort. This stage continues the meaningful and continuous stakeholder engagement to be carried throughout the project development process *(2)*.

1.2.1.3 Preliminary Design

Concepts advancing from the previous stage are further refined and screened during preliminary design. In complex or detailed projects that may impact sensitive areas, the preliminary design and subsequent documentation is used to support complex state or federal environmental clearance activities. Preliminary design builds upon the work and geometric evaluations conducted during alternatives identification and evaluation. Some of the common components of preliminary design are the following *(2)*:

- Horizontal and vertical alignment,
- Typical sections,
- Grading,
- Structures,
- Traffic Operations,
- Signing and pavement markings,
- Illumination,
- Utilities,
- Right-of-Way,
- Environmental Impacts,
- Drainage, and
- Geotechnical considerations.

1.2.1.4 Final Design

The design elements are advanced and refined in final design. The project plans undergo various review periods before completing the final set of plans, specifications, and estimates. During this stage, there is relatively little variation in design decisions as the project advances to the final plan. Functionally, in this stage of the project development process there are few ways of modifying the design plans in a way to substantially affect or attain targeted performance measures *(2)*.

1.2.1.5 Construction

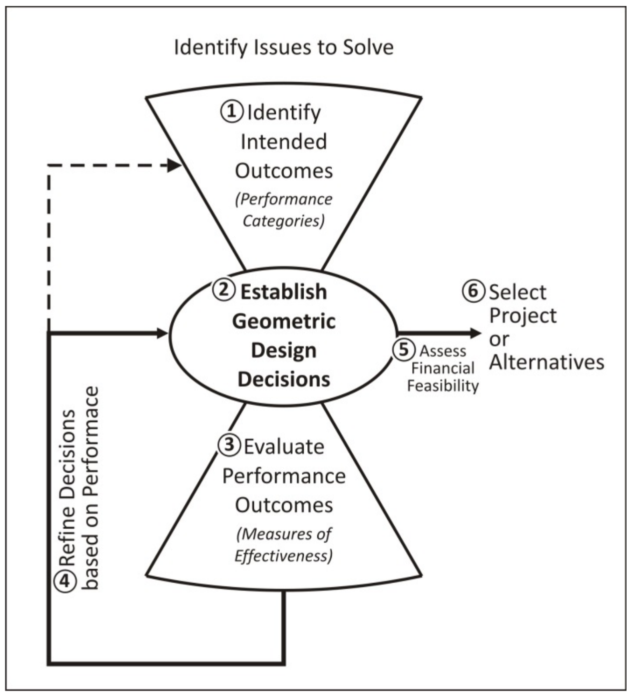
In addition to the final product, construction activities could include geometric design decisions related to temporary roadways, connections, or conditions that facilitate construction activities *(2)*.

1.2.2 Performance-Based Road Design

Incorporating a performance-based road design approach into the road design project development process enables design teams to make informed decisions about the performance tradeoffs. This is especially helpful when developing solutions in fiscally and physically constrained environments. National activities and associated publications, such as Federal Highway Administration's (FHWA) Performance-Based Practical Design initiatives and *NCHRP Report 785, Performance-Based Analysis of Geometric Design of Highways and Streets, (NCHRP Report 785)* have resulted in a framework for how this approach can be executed within a design project *(2, 3)*. While design teams may have been using similar practical design approaches in the past, clear documentation of a performance-based approach can encourage effective problem-solving, collaborative decision-making, and an overall greater return on infrastructure investments.

A fundamental model for this approach documented in *NCHRP Report 785* is shown in Exhibit 1-2 *(2)*.

Exhibit 1-2 Fundamental Model for Performance-Based Analysis for Geometric Design of Highways and Streets ***(2)***



Source: *NCHRP Report 785*

Exhibit 1-2 illustrates the following basic steps in performance-based analysis to inform geometric design. Each step of this approach is further described below *(2)*.

1. **Identify intended outcomes** (desired project performance) and project purpose and need. This may include any number of project context-driven categories helping to identify project objectives. Identifying project purpose and need early in the project development process, such as the planning stage, can help guide the project team as decisions are made in the subsequent stages of the project.
2. **Establish geometric design decisions.** This could include establishing design criteria and developing preliminary designs. A preliminary review of potential design exceptions required for the project may be

identified at this stage. Documenting design decisions and the considerations supporting those choices that result in flexible design solutions is a key component in managing project risk. Additional information on documentation for design exceptions is provided in Chapter 2, Section 2.9.

3. **Evaluate performance outcomes.** This is the point at which the performance outcomes of the geometric design choices are evaluated. Establishing the geometric performance allows an assessment of the effectiveness of the design decision in relation to the project purpose.
4. **Refine decisions based on performance.** Depending on the results of the evaluation of the design performance, there can be an iterative process to refine design decisions to bring resulting performance in line with project purpose. This type of approach can be used as a problem-solving tool throughout a project and a framework for maintaining a consistent project scope throughout each stage of the process.
5. **Assess financial feasibility.** In this step the benefits associated with design choices are assessed to establish the monetary value of the geometric solution compared to the intended project outcomes. Cost estimates and project funding information will be used at this stage to help make project decisions. Additional information on cost estimating is described in Section 1.3.3.
6. **Select project(s) or alternatives.** As project alternatives are deemed viable within the project context, they may be advanced for more detailed evaluations and/or environmental reviews. At this stage of the project, a selected alternative may be carried forward to a final design stage where additional road design details are reviewed and design plans are prepared.

The fundamental model provides a decision making approach that can help the design team to develop and evaluate design choices within each unique contextual design environment. The focus is on performance improvements that benefit the project and system needs and allows decisions to be made based on performance analysis.

The fundamental model provides a decision making approach that can help the design team to develop and evaluate design choices.

Executing this approach involves using relevant, objective data to support the design decisions and developing an analytical approach tailored to the project purpose and need. This will require an awareness of the resources available to quantify specific performance measures or qualitatively describe the anticipated effect of a given roadway, intersection, or interchange design. Examples of performance-based tools that can be used as a resource for conducting a project with this approach are described below:

- American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual (HSM)* provides factual information and proven analysis tools for crash frequency prediction *(4)*. The *HSM* helps users integrate quantitative crash frequency and severity performance measures into roadway planning, design, operations, and maintenance decisions. *HSM* analytical tools allow users to assess the safety impacts of transportation project and program decisions *(2)*.

- The *HSM* predictive tools have been integrated into FHWA's *Interactive Highway Safety Design Model (IHSDM)*. *IHSDM* is a suite of software analysis tools developed by FHWA that are used to evaluate the safety and operational effects of geometric design decisions on highways *(5). IHSDM* applies *HSM* methodologies to estimate safety performance. It can be used to provide estimates of a highway design's expected safety and operational performance and checks existing or proposed highway designs against relevant design policy values *(2).*
- The *Highway Capacity Manual (HCM)*, published by the Transportation Research Board (TRB), presents the operational performance measures and evaluation procedures for various modes and types of facilities. The *HCM* includes methodologies for evaluating the operations of freeways, weaving areas, freeway/ramp junctions, two-way two-lane facilities, and intersections *(6)*.
- MDT's *Safety Information Management System (SIMS)* is a database and analysis system that allows users to screen the roadway network and complete reviews of specific locations using *HSM* tools and methodologies. This system provides increased access to crash data and advanced crash data query capabilities. *SIMS* incorporates many roadway elements into the database which allows for comparisons of crashes versus roadway characteristics. In addition, this system allows tracking of safety projects for before and after evaluations. Additional information on using this system should be coordinated with the Traffic and Safety Bureau.

In addition, *NCHRP Report 785* (Section 4.4.1) contains table summaries to help identify the available resources for evaluating the performance of roadway segments and nodes (intersections and interchanges) as it relates to various project priorities. Other performance-based resources available are supplemented with spreadsheet or software tools to help expedite their application, and some include graphical representations or table summaries of the relationships to provide guidance early in a project's development *(2)*.

Performance-based road design provides a clear way to document decisions and the justification for these choices.

A performance-based road design approach can be beneficial to executing design decision documentation. The steps taken within this approach help identify the need for design exceptions early in project development. It provides a clear way to document design decisions and the considerations supporting those choices that result in a flexible design solution. Documenting design decisions helps manage tort liability risk. Chapter 2, Section 2.9 provides additional information on MDT's design exception process and considerations.

The information in this section is consistent with the ideas and values presented in the *MDT Context Sensitive Solutions Guide (MDT CSS Guide)*. The *MDT CSS Guide* and the performance-based road design approach emphasize agency and community values and considers tradeoffs in decision making based on available funding. The *MDT CSS Guide* can be a valuable resource for gathering additional information about public involvment, balancing tradeoffs, and methods for reaching desired project outcomes *(7)*.

1.2.3 MDT Project Development Process

The MDT project development process is similar to the project development process described in Section 1.2.1. However, the design activities within each stage may differ from other State agencies and the nomenclature used is specific to MDT. The majority of MDT projects are developed from the planning stage to the construction stage by the same design team. The typical activities within a MDT project are executed through four primary stages: *Scoping, Design, Right-of-Way, and Construction*. Exhibit 1-3 illustrates where MDT's project development process, the nationally recognized project development process, and performance-based road design approach coincide with each other.

The typical activities within a MDT project are executed through three primary stages: *Scoping, Design and Right-of-Way*.

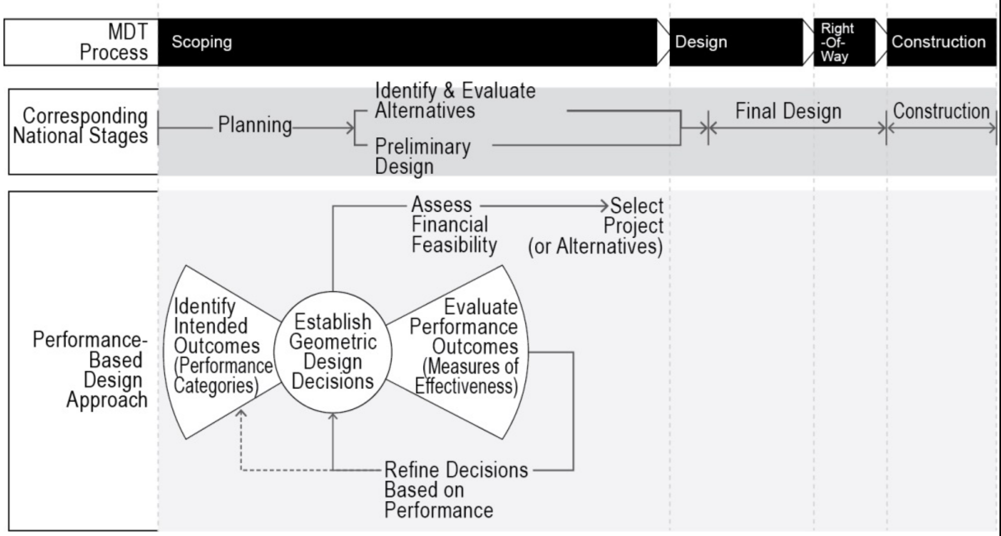


Exhibit 1-3
Relationship between Project Development Processes

The following sections describe the MDT-specific stages, design activities that occur within each stage, and how these activities relate to the representative national project development process. Some of the activities shown below may only occur on capital improvement projects designed by MDT. Projects with a reduced scope may have different or fewer design activities. There are some projects that may include a planning stage prior to the scoping stage. Design projects will require coordination between multiple disciplines and departments internal and external to MDT. The discussion below provides an overview of the road design activities. There are other activities that occur within each project stage for various other disciplines.

Additional information on internal and external MDT coordination is described in Section 1.3.

1.2.3.1 MDT Scoping Stage

The design team tasks within the MDT Scoping Stage are described below. Project initiation activities occur prior to the Preliminary Field Review (PFR) and may include identifying the project catalyst and funding source, initiation of stakeholder engagement, and identifying the project purpose and need. Upon project nomination, the following tasks within this stage are completed:

- Conduct Preliminary Field Review (PFR)
    - Continue Stakeholder Engagement

    - Identify Project Context
    - Clarify Intended Outcomes
    - Refine Purpose and Need
    - Prepare PFR Report
- Obtain Public Input
- Conduct Survey
- Gather Design Input
- Conduct Preliminary Plan Preparation
- Establish/Review Alignment and Grade
- Prepare Scope of Work (SOW) Report
- Approve Scope of Work

The MDT Scoping Stage corresponds to the Planning, Alternatives Identification and Evaluation, and Preliminary Design Stages of the representative national project development process.

Corresponding National Planning Stage

The portion of the MDT Scoping Stage that corresponds to the national Planning Stage is not as extensive as other stages throughout the project and relies on other bureaus and units to provide operational and safety analyses. The Planning Stage corresponds to the Preliminary Field Review (PFR). Prior to the PFR, there are other planning activities that occur including considerations for project catalyst, initial stakeholder engagement, and project context. A clear understanding of these considerations helps frame the basis for outlining the project desired outcomes and project purpose and need.

As described previously in Section 1.2.2, establishing the project purpose and need early in the project development can help the design team make decisions throughout the project and is a key component of executing performance-based design approach. The purpose and need identification is followed by determining the preliminary scope and budget, and prioritizing the project for inclusion in the construction program. Once a project becomes a priority, funding is programmed and a design team is assigned that will complete the project. The Preliminary Field Review, and subsequent PFR Report, typically completes the Planning Stage and begins the next stages for the design.

Corresponding National Alternatives Identification & Evaluation, and Preliminary Design Stages

NEPA documentation may be completed within the Planning Stage and will be completed by the end of the Scoping Stage.

Within the MDT Scoping Stage, the two stages of the national project development process, Alternatives Identification and Evaluation and Preliminary Design, are generally executed concurrently. The Scoping Stage provides the greatest opportunity for evaluating design alternatives and understanding the tradeoffs for each design alternative. In this part of the Scoping Stage, the design team gathers all data and project information, such as surveys, public input, and anticipated future conditions, that are necessary to advance the project into final design. At this stage of the process, a performance-based road design analysis approach may help provide a clear framework for making design decisions and selecting alternatives consistent with the intended project outcomes. Performance-based analysis tools, such as the *HSM* and *IHSDM* can help provide quantitative data for supporting design decisions *(4, 5)*.

During the Scoping Stage, the design team completes the necessary documentation for the National Environmental Policy Act (NEPA) and Montana Environmental Policy Act (MEPA), and the design is advanced to allow for the Scope of Work to be finalized and approved. Design plans are advanced to an approximate 30-percent level of detail, including proposed lines and grades, mainline grading and surfacing design and preliminary design of major drainage structures. In addition, avoidance measures for impacts to sensitive areas have been taken into account and documented.

Proposed horizontal and vertical alignments are developed and approved through the Alignment and Grade Review process during the Scoping Stage.

1.2.3.2 MDT Design Stage

The MDT Design Stage includes the following design team tasks:

- Prepare Plans for Plan-in-Hand
- Conduct Plan-in-Hand Inspection
- Determine Construction Limits

Corresponding National Final Design Stages

The beginning of the MDT Design Stage will typically include some activities that may correspond to the end of the corresponding national stages of Alternatives Identification and Evaluation and Preliminary Design, as shown in Exhibit 1-3.

The remainder of the MDT Design Stage corresponds to the Final Design Stage of the representative national project development process. The MDT Design Stage involves refining the design to the point where final construction limits and impacts are known. The design is advanced to an approximate 80-percent level of detail, including designing features that have the potential to impact construction limits, such as irrigation, approaches, or widening for turn lanes and guardrail. Final construction limits are provided to all units where mitigation of impacts are required, which is typically the Right-of-Way, Utilities, and Environmental Design Units. During this stage, minimizing impacts to known sensitive areas occurs and those that could not be avoided are documented. MDT's corresponding Final Design Stage continues to the next MDT design stage, *Right-of-Way*, shown below.

Final construction limits are provided to all units where mitigation of impacts are required, which is typically the Right-of-Way, Utilities, and Environmental Design Units.

1.2.3.3 MDT Right-of-Way Stage

The MDT Right-of-Way Stage includes the following design team tasks:

- Design Miscellaneous Features
- Conduct Final Plan Review
- Prepare Final Plan Updates and Revisions
- Check Plans
- Submit to Contract Plans

Changes to plans due to right-of-way negotiations or contractor/construction proposals should be checked to ensure the overall purpose and need of the project is still being met.

- Coordinating with:
    - Right-of-Way Acquisition
    - Utility Agreements and Relocation
    - Environmental Permits

Corresponding National Final Design and Construction Stages

The MDT Right-of-Way Stage also occurs within the Final Design Stage of the project development process. During the Right-of-Way Stage, plans are completed, all impacts are mitigated and permitted, and the right-of-way required for the project is acquired.

1.2.3.4 MDT Construction Stage

Once the project reaches the MDT Construction Stage, the Construction Bureau executes the project construction. The road design team has limited involvement in the Construction Stage, other than to provide support to the Construction Bureau by answering design-related questions and assisting with change orders.

1.3 MDT ROAD DESIGN PROCESS AND COORDINATION

Section 1.2 provided an overview of the nationally recognized project development process stages, an overview of performance-based road design and described the MDT-specific activities and project development stages. The purpose of Section 1.3 is to provide additional details on the MDT road design process and coordination that occurs on projects. The following information will introduce the MDT internal and external units and provide an overview of engineering management, cost estimating and project reports.

1.3.1 Road Design Coordination

The design team must coordinate with many units internal and external to MDT.

During the development of a road design project, the design team must coordinate with many units internal and external to MDT. This section provides additional resources for understanding how the various units within MDT coordinate during various stages of the project. The design team works with representatives from many other groups and disciplines.

1.3.1.1 Internal

Throughout the various stages of a project, the design team will communicate and work with many other MDT internal units outside of the Engineering Division. The following link on the MDT Website provides the organizational chart for all divisions and departments within MDT to provide an overview of the various groups the design team may coordinate with throughout a project.

MDT Organizational Chart

The following links provide the design team activities within the Engineering Project Scheduler (EPS):

MDT EPS Design Team Activities (consultant projects)

Additional information regarding internal MDT coordination, organizational structure, and group interaction is described in Appendix D.

An overview of the Engineering Division is described below, which includes information about the Preconstruction and Construction programs. Environmental Services is located within the Rail, Transit and Planning Division. Within the Districts, there are parallel coordination activities.

Preconstruction

Preconstruction involves planning and developing the details of construction projects. This includes determining the project location and design features, gathering public input and working with local officials, acquiring property for right-of-way and relocating utilities. Preconstruction functions include:

- Bridge
- Consultant Design
- District Staff
- Engineering Information Services/CADD
- Highways
- Hydraulics
- Survey
- Right-of-Way
- Traffic and Safety

Construction

Construction includes Construction Engineering, Construction Administration, Contract Plans, Materials, Pavement Analysis, and Geotechnical. Construction is responsible for processing construction contracts for award to private contractors and managing all construction activities on all State-administered projects. The design team also coordinates with construction staff during project design.

Environmental Services

The Environmental Services Bureau is responsible for identifying cultural and environmental resources; estimating potential impacts; recommending avoidance, minimization, and mitigation features and obtaining permits associated with the location, design, construction, operation and maintenance of transportation projects within Montana. Bureau staff members are an essential part of the project development team. Their work addresses a variety of applicable state, federal, and tribal laws that require consideration of social, economic, and environmental impacts and protection of important resources *(7)*.

Specific individuals and departments that the design team will coordinate with to submit project materials and obtain review comments are further described in the Distribution Section of the MDT Project Reports. A link to the MDT Project Reports is provided in Section 1.3.4.

1.3.1.2 External Partners

There are various partners external to MDT that may be involved in planning, developing, and implementing the transportation system. Federal Highway Administration (FHWA) is the primary federal partner, which provides a majority of the funding for transportation projects in Montana. Additional information on the external resource, regulatory, and local agencies that MDT may coordinate with on a project are described below, and can also be found in the *MDT CSS Guide (7)*.

1. **Federal Highway Administration (U.S. Department of Transportation).** The Federal-aid highway program is administered by FHWA, providing financial and technical assistance to the States and metropolitan planning organizations to plan, construct, and improve the National Highway System and other roads and bridges eligible for federal aid. The program also addresses economic and social factors affected by transportation systems and infrastructure development. Assistance is available for communities through State-administered, federally-assisted planning, development, safety and operational funding. The program fosters the development of a safe, efficient, and effective highway and intermodal system nationwide. FHWA has primary responsibility for compliance with the National Environmental Policy Act and the Uniform Relocation Assistance Act, as examples, and other statutory and regulatory requirements.
2. **U.S. Fish and Wildlife Service (U.S. Department of the Interior).** The U.S. Fish and Wildlife Service work to protect threatened and endangered species, migratory birds, freshwater fish and wildlife habitats. They administer provisions of the Endangered Species Act, Bald and Golden Eagle Protection Act, Migratory Bird Treaty Act, and other wildlife laws.
3. **U.S. Forest Service (U.S. Department of Agriculture).** The U.S. Department of Agriculture Forest Service's fundamental responsibility is focused on stewardship and sustainability of the National Forests and the associated resources.
4. **Bureau of Land Management (U.S. Department of Interior).** It is the mission of the Bureau of Land Management (BLM) to sustain the health, diversity and productivity of the public lands for the use and enjoyment of present and future generations. The BLM's task is to recognize the demands of public land users while addressing the needs of traditional user groups.
5. **U.S. Army Corps of Engineers (U.S. Department of Defense).** The United States Army Corps of Engineers is primarily responsible for regulating the placement of fill material into waters of the U.S. by authority of the Clean Water Act.

6. **U.S. Environmental Protection Agency (EPA).** The mission of the EPA is to protect human health and the environment. In Montana, the EPA has delegated much of the regulatory authority to the State but maintains oversight responsibility for a variety of programs, such as the Clean Water Act and the Resource Conservation and Recovery Act (Superfund sites). The EPA has oversight for environmental regulation on sovereign Indian lands.
7. **Montana Department of Environmental Quality (DEQ).** The DEQ is responsible for ensuring clean air, water, and land in the state and for protecting Montana citizens' constitutional rights for a clean and healthful environment. As a regulatory agency, the DEQ is responsible for enforcing various state environmental regulations and administering a number of federal environmental protection laws, including the Clean Air Act, the Clean Water Act, and the Resource Conservation and Recovery Act. The Montana DEQ reviews MDT projects to ensure that they have the necessary environmental permits and clearances.
8. **Montana Department of Fish, Wildlife & Parks (FWP).** The Montana FWP's primary role is advising and providing technical information regarding wildlife and fish. The FWP administers the Montana Stream Protection Act and oversee properties acquired or improved with funds from the land and water conservation fund (Section 6(f)). MDT has agreements in place with the FWP to provide consultation services, and the FWP is also a participant in interagency coordination for transportation projects under development.
9. **Montana Department of Natural Resources & Conservation (DNRC).** The Montana DNRC deals with water resource issues. Their programs include groundwater protection, floodplain management, stream channel protection, water allocations/water rights, and water planning.
10. **Montana State Historic Preservation Office (SHPO).** The Montana State Historic Preservation Office is a division of the Montana Historical Society. The mission of SHPO is to preserve Montana's historic, archaeological and cultural places. The role of the State Historic Preservation Office in federal project review is to reflect the interests of the State and its citizens in the preservation of Montana's rich cultural heritage through the State Antiquities Act, Section 106 of the National Historic Preservation Act, Section 4(f) of the Department of Transportation Act.
11. **Tribal Governments.** The Montana Department of Transportation regularly works with several tribal governments. This would include a project that impacts land owned by a tribe or provides access to tribal land. In these cases, MDT coordinates with the tribe and tribal government to execute the design project based on established agreements.
12. **Local Government Agencies.** MDT coordinates with local cities and counties on MDT projects that include both State and non-State facilities. These agencies will work collaboratively to ensure that

appropriate design processes and objectives are accomplished by the collective design team.

13. **Consultants.** MDT may use a consultant for a road design project. When a consultant is used, the Consultant Design Bureau is the primary contact with the consultant. The Highways Bureau will provide technical support on the project and review the plans prepared by the consultant.
14. **Railroads.** Railroad departments and authorities may be involved in a project that involves a roadway facility that crosses through or is adjacent to an existing railroad.

1.3.2 Engineering Management

The Preconstruction Engineer is ultimately responsible for managing the delivery of project plan packages to construction as an overall program. District Administrators, through District Preconstruction and Headquarters design managers, are responsible for project delivery. The Engineering Information Services Section (EISS) monitors, maintains and updates the EPS (Engineering Project Scheduler) program which is used to schedule project tasks and monitor preconstruction manpower needs. The following sections provide an overview of the types of managers, correspondence, meetings, project work type codes, and quality assurance and quality control.

1.3.2.1 Types of Managers

Project Design Managers (PDMs) are assigned the responsibility to monitor the design of roadway projects from project inception to when they are delivered to contract. Functional Managers (FMs) are assigned the everyday responsibility of completing the project tasks set forth in the EPS.

PDMs reside primarily in the Highways Bureau, Bridge Bureau, Consultant Design Bureau, Traffic and Safety Bureau, and District offices. The Project Design Manager may act as both PDM and FM, with other FMs residing throughout the Department. The Right of Way Bureau, Environmental Services Bureau, and Construction Engineering Bureau, all have FMs assigned to project activities.

1.3.2.2 Correspondence

As described in Section 1.3.1, the design team will correspond with many people internal and external to MDT. In-house memoranda (paper and electronic) are used by MDT to provide written, interdepartmental information between the various Bureaus, Sections, and Districts. They are used to distribute project reports, process approval requests, request project information, submit project information, distribute policies and for informational purposes.

The design team will likely have correspondence with groups outside of MDT, such as federal, state or local agencies. The design team should work with the project manager to determine the appropriate signatures and policies for out-going correspondence.

Specific individuals and departments that the design team will coordinate with to submit project materials and obtain review comments are further described in the Distribution Section of the MDT Project Reports. A link to the MDT Project Reports is provided in Section 1.3.4.

1.3.2.3 Meetings

Design projects will include multiple meetings to provide information, obtain information and coordinate with other disciplines or teams. It is imperative that all meetings be well planned, attended by the proper individuals, and the information well documented and disseminated to the affected people in a timely manner.

Project Review Meetings are conducted throughout the course of a project to allow others to review the project design and make design decisions. Formal review meetings include the Preliminary Field Review, the Alignment & Grade Review, the Plan-in-Hand Review and the Final Plan Review. In addition, informal meetings are often initiated to gather or disseminate information between the affected parties.

1.3.2.4 Project Work Type Codes

All project documents are required to provide the project work type number in the subject portion of a memorandum. A listing of the standardized project work type codes and definitions used by MDT can be found at the following links on the MDT Website.

Project Work Type Codes

Project Work Type Definitions

The applicable project work type number will be determined when the project is nominated and is verified during the PFR process. It may be revised for the Scope of Work Report.

Changes to the project work type after the Scope of Work Report has been approved require developing a Scope of Work amendment.

1.3.2.5 Quality Assurance/Quality Control (QA/QC)

Establishing an effective and consistent Quality Assurance/Quality Control (QA/QC) process can help ensure each design meets the appropriate level of detail and quality necessary to complete the objectives of the project. This process may include multidisciplinary reviews, peer reviews, performance-based analysis, Value Analysis, and establishing standardized reports. Following the established process and active participation in the QA/QC process can lead to effective and timely projects that accomplish the desired outcomes and meet the quality expected from MDT. If project issues arise, there should be an emphasis on collaborative problem-solving to identify an approach to resolve the issues to allow the project to continue forward.

1.3.3 Cost Estimating

The following information provides a summary of the various pre-construction cost estimates required during project development and the procedures for developing these estimates. Additional cost estimating information and procedures is provided on the MDT Website at the following location:

Cost Estimating Information

Project estimates are used by Fiscal Programming and the Districts to develop the 5-year Tentative Construction Plan (TCP, also known as the *Red Book*) to ensure that sufficient funds are available for construction. The TCP is MDT's best estimate of when projects will be let and what the costs will be. The Highways and Engineering Division and the Districts use the TCP to prioritize project design. Accurate cost estimates ensure that the design team is working on the appropriate projects. If cost estimates are too low, there may not be sufficient funds to complete the designed projects. As a consequence, resources will be focused on projects that may not be let to contract until the next fiscal year. If cost estimates are too high, the TCP will under-estimate the number of projects designed for the fiscal year. This could result in inadequate time to complete designs or even the loss of federal funding.

During project development, several cost estimates are prepared to determine and refine the expected project construction costs. Cost estimates are typically developed at the following project stages:

1. **Project Programming/Preliminary Field Review.** The District Office is responsible for nominating projects to be included on MDT's Program of Projects. When the District Office submits these nominations, they are also required to submit a conceptual cost estimate for each project. This estimate should be reviewed and revised, if necessary, during the PFR and documented in the PFR Report.
2. **Alignment and Grade Review/Report**. The design team is responsible for determining the first detailed construction cost estimate at this stage of project development.
3. **Scope of Work Report.** If a project does not have an Alignment and Grade Review, the design team will develop the first construction cost estimate which will be included in the Scope of Work Report.
4. **Plan-in-Hand Report.** The design team is responsible for updating the construction cost estimate for the Plan-in-Hand. At this stage of project development, the majority of the project quantities should be available.
5. **Project Scope Changes**. Whenever the scope of the project changes, the design team will be responsible for determining a new construction cost estimate.
6. **Final Plan Review Report.** The final cost estimate will be reviewed during the review of the final plans.
7. **Annual Updated Estimates.** Estimates are updated annually to support *Red Boo*k preparation, as needed.

8. **Engineer's Estimate.** The Engineer's Estimate is developed by the Contract Plans Bureau for programming Construction and Construction Engineering funds, and for comparative purposes for bid letting.

Additional details regarding quantity summaries are provided in Chapter 13.

1.3.4 Project Reports

Project reports are developed to identify potential project-related issues, document alignment determinations, provide an overview of the design features, and outline an in-depth review of all items contained in the project plans and special provisions. MDT road design projects typically develop the following types of project reports throughout the course of the project:

- Preliminary Field Review Report
- Combined Preliminary Field Review Report and Scope of Work Report
- Alignment and Grade Review Report
- Scope of Work Report
- Plan-in-Hand Report
- Final Plan Review Report

Additional information regarding the format, content, and how to prepare the project reports to provide consistent, accurate and appropriate project information can be found at the following link on the MDT Website.

Project Reports

In some cases, a project may require special reports to document unique project development approaches and project characteristics. For these instances, the design team should consult with the project manager to identify an appropriate format and content for the report.

1.4 MULTIMODAL DESIGN

Roadway facilities should be designed and operated to enable safe access for all users, including pedestrians, bicycles, motorists, and transit riders of all ages and abilities. The design team should understand the difference between "accommodating" versus "designing for" a given mode and apply consistent principles within the project context. The multimodal design considerations depend on the intended function of the corridor. For example, if a roadway is intended to be designed primarily for mobility for motorized vehicles, the design may "accommodate" other users, such as pedestrians and bicycles. However, if a roadway is intended to primarily serve non-auto users, with mobility for motorized vehicles as a lower priority, the corridor should be "designed for" multimodal users.

Understand the difference between "accommodating" versus "designing for" a given mode and applying consistent principles within the project context.

Pedestrian facilities should be designed to be accessible to all users, regardless of ability. The United States Access Board provides additional resources on accessibility and specific requirements for Accessible Public Rights of Way *(19).*

Chapter 7 of this manual describes the integration of multimodal design in the overall design process. This chapter includes the design principles and approach for a multimodal design, including pedestrians, bicycles, shared use paths, and transit. It also addresses accessibility as it relates to special consideration given to pedestrians with disabilities including accommodating pedestrians with vision or mobility impairments.

1.5 COORDINATION WITH OTHER PUBLICATIONS

The *RDM* is not intended to present all information which may be needed by the design team on a specific project. While the *RDM* does include the majority of the road design information for the vast majority of projects, there may be specific projects or project elements that require referencing other publications to perform a fully comprehensive analysis of the project. The following section provides a summary of the national publications and MDT department publications that can provide additional resources for the design team throughout the design project. Refer to the most recent version of the publications listed below.

1.5.1 National Publications

There are many national publications that can provide resources for the design team throughout a project. Below is a brief description of some relevant national publications, and its application on MDT road design projects. There may be other AASHTO and FHWA documents that the design team may consider to gain additional design information and guidance.

1.5.1.1 American Association of State Highway and Transportation Officials (AASHTO) A Policy on Geometric Design of Highways and Streets (Green Book)

The AASHTO *A Policy on Geometric Design of Highways and Streets*, more commonly known as the *Green Book*, discusses the nationwide policies, practices, and guidance for the geometric design of highways and streets. It is intended to present a consensus view on the most widely accepted approach to the design of a variety of geometric design elements, including design speed, horizontal and vertical alignment, cross-section widths, intersections, and interchanges *(9)*.

Several of the chapters within the *RDM* address geometric design elements. The *RDM*'s geometric design controls and criteria have been based on the *Green Book* but tailored to the prevailing climate, topography and practices within Montana. Also, the *RDM* is intended to clarify, where needed, specific presentations in the *Green Book* and to discuss geometric design information not presently included in the *Green Book*. Where conflicts may exist between the *RDM* and the *Green Book*, the *RDM* will govern.

1.5.1.2 AASHTO Roadside Design Guide

The AASHTO *Roadside Design Guide* presents the nationwide policies, practices and guidance for roadside safety along highways and streets. It is intended to present a consensus view on the most widely accepted approach to providing a reasonably safe roadside for run-off-the-road vehicles. The *Roadside Design Guide* discusses clear zones, drainage appurtenances, sign and luminaire supports, roadside barriers, median barriers, bridge rails, crash cushions and roadside safety within construction work zones. The overall objective of the *Roadside Design Guide* is to recommend an appropriate roadside safety treatment for specific sites considering the consequences of run-off-the-road accidents, specific roadway features (e.g., traffic volumes, design speed, and roadside topography) and construction and maintenance costs *(10)*.

Chapters in the *RDM* that address roadside safety include:

- Chapter 9: Roadside Safety; and
- Chapter 10: Work Zone Traffic Control.

The roadside safety criteria in these chapters are based on the criteria presented in the *Roadside Design Guide* but tailored to the prevailing practices and conditions in Montana. Also, the *RDM* is intended to clarify, where needed, the presentations in the *Roadside Design Guide* and to discuss roadside safety information not included in the Roadside Design Guide. Where conflicts may exist between the *RDM* and the *Roadside Design Guide*, the *RDM* will govern.

1.5.1.3 AASHTO Model Drainage Manual

The AASHTO *Model Drainage Manual (MDM)* presents the nationwide criteria for the hydrologic and hydraulic design of drainage appurtenances for highway projects. The *MDM* discusses the most commonly used hydrologic methods (such as the Rational Method), and it discusses the hydraulic design of open channels, culverts, bridges, closed drainage systems, energy and dissipaters. The *MDM* supersedes, incorporates or references FHWA Hydraulic Engineering Circulars and Hydraulic Design Series publications. The overall objective of the *MDM* is to present hydraulic design criteria for highway drainage features which properly consider the probability of an extreme hydraulic event, the consequences of that event and the costs of providing a drainage system which will accommodate the event *(11)*.

The Hydraulics Section is typically responsible for the hydraulic design of drainage appurtenances for all roadway projects under the jurisdiction of the Department. The design is based on criteria in the AASHTO *Model Drainage Manual*, *MDT Hydraulics Manual* and general MDT practices in hydrology and hydraulics *(12)*. Where conflicts exist between the *MDM* and MDT practices, the Hydraulics Section will determine the proper application.

Chapter 11 primarily discusses structural requirements for drainage appurtenances (e.g., maximum heights of fill and wall thicknesses for pipe culverts). It does not address hydrology and hydraulics.

1.5.1.4 AASHTO Policy on Design Standards – Interstate Highways

AASHTO's *Policy on Design Standards – Interstate Highways* provides design guidance for designing the nation's highways with an importance on safety, permanence, utility, and flexibility to provide for predicted growth in traffic *(13)*. This document provides the minimum standards for interstate highway segments constructed on new right-of-way and segments undergoing complete reconstruction along existing right-of-way. The current editions of *AASHTO's A*

Policy on Geometric Design of Highways and Streets shall be used as design guides where they do not conflict with these standards.

1.5.1.5 AASHTO Practical Guide to Cost Estimating

AASHTO's *Practical Guide to Cost Estimating* provides State Departments of Transportations (DOTs) guidance on developing realistic estimates of project cost. This document provides information anticipating cost impacts that may occur due to changes in project scope, available resources, and national and global market conditions. This publication provides "practical" guidance that serves those charged with the development of DOT cost estimates and with the management of the estimating process. This guidebook has two parts. Part I focuses on key cost-estimate techniques and Part II focuses on cost management activities *(14)*.

1.5.1.6 Highway Capacity Manual (HCM)

The *Highway Capacity Manual (HCM)*, published by the Transportation Research Board (TRB), presents the nationwide criteria for performing capacity analyses for highway projects. The *HCM* includes methodologies for freeways, weaving areas, freeway/ramp junctions, two-way two-lane facilities, and intersections. The basic objective of the capacity methodologies in the *HCM* is to determine the necessary configuration and dimensions of a specific highway element to accommodate the projected traffic volumes at a given level of service *(6)*.

The Traffic and Safety Bureau performs all needed capacity analyses for MDT road design projects. The *HCM* is used for all analyses with some adjustments for local highway capacity factors.

1.5.1.7 Highway Safety Manual (HSM)

The *Highway Safety Manual (HSM)*, published by AASHTO, presents a variety of methods for quantitatively estimating crash frequency or severity at a variety of locations. This manual provides tools to conduct quantitative safety analyses, allowing for safety to be quantitatively evaluated alongside other transportation performance measures such as traffic operations, environmental impacts, and construction costs *(4)*.

The *HSM* may be used by the design team to identify quantitative data for supportive design decisions when executing a performance-based approach and can help provide documentation for design decisions that require design exceptions.

1.5.1.8 AASHTO Guide for the Development of Bicycle Facilities

The AASHTO *Guide for the Development of Bicycle Facilities* provides information and guidelines for designing bicycle facilities in various design environments. The intent is to provide sound guidelines that result in facilities that meet the needs of bicyclists and other roadway users. While suggested minimum dimensions are provided, there is also sufficient flexibility permitted to encourage designs that are sensitive to local context and incorporate the needs of bicyclists, pedestrians, and motorists *(15)*.

Chapter 7 and Chapter 8 provide design principles and considerations for designing facilities for all users. The AASHTO *Guide for the Development of Bicycle Facilities* was used to develop the material described in the *RDM* and can be used as an additional resource when designing bicycle facilities.

1.5.1.9 AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities

The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* provides design guidance for pedestrian facilities and helps identify effective measures for accommodating pedestrians on public rights-of-way *(16)*.

Chapter 7 and Chapter 8 provide design principles and considerations for designing facilities for all users. The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* was used to develop the material described in the *RDM* and can be used as an additional resource when designing pedestrian facilities.

1.5.1.10 Transportation Research Board Access Management Manual

TRB's *Access Management Manual* provides technical information on access management techniques for the systematic control of the location, spacing, design, and operation of driveways, median openings, street connections, and interchanges to a roadway. This manual integrates planning and engineering practices with the transportation and land use decisions that contribute to access outcomes *(17)*.

Access control on MDT facilities is described in Chapter 2, Section 2.7. TRB's *Access Management Manual* can serve as a resource, in addition to the *MDT Approach Manual for Landowners and Developers (18).*

1.5.1.11 Guidance on the 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design

The Department of Justice's revised regulations for Titles II and III of the Americans with Disabilities Act of 1990 (ADA) were published in the Federal Register on September 15, 2010. These regulations adopted revised, enforceable accessibility standards called the 2010 ADA Standards for Accessible Design, "2010 Standards." On March 15, 2012, compliance with the 2010 Standards was required for new construction and alterations under Titles II and III. March 15, 2012, is also the compliance date for using the 2010 Standards for program accessibility and barrier removal *(8)*.

Guidance on the 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design can be used as a resource for the design team to address accessibility considerations and ensure the design meets the needs of all users.

1.5.1.12 United States Access Board Public Rights-of-Way Accessibility Guidelines (PROWAG)

The *U.S. Access Board PROWAG Guidelines* should be used by the design team to design sidewalks, street crossings, and other elements in the public right-of-way, such as curb ramps. The guidelines address various issues, including access for blind pedestrians at street crossings, wheelchair access to on-street parking, and various constraints posed by space limitations, roadway design practices, slope, and terrain. The guidelines include pedestrian access to sidewalks and streets, including crosswalks, curb ramps, street furnishings, pedestrian signals, parking, and other components of public rights-of-way *(19)*.

The *U.S. Access Board PROWAG Guidelines* can be used as a resource for the design team to address accessibility considerations and ensure the design meets the needs of all users.

1.5.1.13 Manual on Uniform Traffic Control Devices (MUTCD)

The *Manual on Uniform Traffic Control Devices (MUTCD)*, published by FHWA in coordination with the National Committee on Uniform Traffic Control Devices, presents nationwide criteria for the selection, design and placement of all traffic control devices. This includes highway signs, pavement markings and traffic signals. The basic objective of the *MUTCD* is to establish an effective means to convey traffic control information to the driver for uniform application nationwide. The *MUTCD* information is divided into four categories — standard, guidance, option and support. These categories are used to establish the proper application of *MUTCD* criteria for all public roads and streets within the U.S. *(20)*.

The Traffic and Safety Bureau is responsible for the use of traffic control devices on all projects under the jurisdiction of MDT. MDT has adopted the use of the *MUTCD* in its entirety, including the context of its presentation. The *RDM Detailed Drawings* present additional information on traffic control devices which supplements the criteria in the *MUTCD*.

1.5.2 MDT Publications

MDT has prepared many publications in addition to the *RDM* which may apply to a road design project. MDT Publications can be accessed through the following link on the MDT Website.

Montana Department of Transportation Publications

In addition, the design team should identify if there are applicable design memoranda that should also be referenced for additional updated design information. MDT design memoranda are provided at the following link on the MDT website:

MDT Design Memoranda

1.6 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.
2. Ray, B., Ferguson, E., Knudsen, J., and Porter, R.J. *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets.* Transportation Research Board of the National Academies, Washington, D.C., 2014.
3. Federal Highway Administration (FHWA). Performance-Based Practical Design Website: http://www.fhwa.dot.gov/design/pbpd/
4. American Association of State Highway Transportation Officials (AASHTO). *Highway Safety Manual (HSM)*. AASHTO, Washington, D.C., 2010.
5. FHWA. *Interactive Highway Safety and Design Model (IHSDM)*. FHWA, Washington, D.C., 2003.
6. Transportation Research Board (TRB). *Highway Capacity Manual (HCM).* Transportation Research Board of the National Academies, Washington, D.C., 2010.
7. MDT. *MDT Context Sensitive Solutions Guide*. MDT, Helena, MT, 2015.
8. Department of Justice. *Guidance on the 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design.* Department of Justice, 2010.
9. AASHTO. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 2011.
10. AASHTO. *Roadside Design Guide.* AASHTO, Washington, D.C., 2011.
11. AASHTO. *Model Drainage Manual*. AASHTO, Washington, D.C., 2005.
12. MDT. *MDT Hydraulics Manual.* Helena, MT: MDT, 2015.
13. AASHTO. *Policy on Design Standards – Interstate System.* AASHTO, Washington, D.C., 2005.
14. AASHTO. *Practical Guide to Cost Estimating, 1st Edition.* AASHTO, Washington, D.C., 2013.
15. AASHTO. *Guide for the Development of Bicycle Facilities.* AASHTO, Washington, D.C., 2012.
16. AASHTO. *Guide for the Planning, Design, and Operation of Pedestrian Facilities.* AASHTO, Washington, D.C., 2004.
17. TRB. *Access Management Manual.* Transportation Research Board of the National Academies, Washington, D.C., 2003.
18. MDT. *Approach Manual for Landowners and Developers.* MDT, Helena, MT, 2013.
19. United States Access Board. *Public Right-of-Way Accessibility Guidelines (PROWAG).* Website: http://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way
20. FHWA. *Manual on Uniform Traffic Control Devices (MUTCD).* FHWA, Washington, D.C., 2009.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 2

Basic Design Controls

September 2016

Contents

Chapter 2

Basic Design Controls

2.1 INTRODUCTION

Roadway design is predicated on basic controls that establish the overall objective of the roadway facility and identify the basic purpose of the roadway project. Understanding the distinction between basic design controls and geometric design criteria is fundamental to executing a design approach that meets the desired outcomes of a project. **The design controls are attributes, values, or qualities that influence discrete geometric element dimensions or considerations. Design criteria are dimensions and values that meet design control needs, such as curve radius, cross section, and merge lengths.**

The performance-based design approach guides the design team to take the intended project outcome into account when establishing the design controls and associated design criteria on a project-by-project basis.

Chapter 2 of the *MDT Road Design Manual (RDM)* outlines the basic design controls for the criteria that impact roadway design. This includes a discussion on the functional classification system, speed, traffic volume controls, access control, sight distance, and the design exception process. *MDT Geometric Design Standards* present design criteria and references the design controls in Chapter 2 for more information on each design element *(1)*. Identifying the controls that impact the criteria can help the design team understand how the design decisions can impact the performance measures related to the overall project desired outcomes.

The design controls and associated criteria provide a platform for the design team to make thoughtful evaluations of the project needs and context. Design decisions may result in changing various design criteria to achieve the overall purpose of the project and/or more effectively serve the various users of the roadway. The design exception process is meant to help document the design decisions (changes to criteria based on project context) and provide a framework for balancing the importance of geometrics, safety, and operations, as well as considering tradeoffs. A performance-based design approach and the tools presented in this approach, provide an effective way to evaluate the performance measures, understand the tradeoffs of design decisions, and document the process.

2.1.1 Land Use and Terrain

Roadway topography and surrounding land use can affect basic design controls.

The roadway topography and surrounding land use can affect basic design controls, such as the design speed for the roadway. To determine the surrounding land use, the following descriptions are used:

1. **Urban Areas.** Those places within boundaries set by the responsible State and local officials or a place that has urbanized characteristics. Urban areas have three subcategories:
   a. **Urbanized Areas**. Those areas with a population greater than 50,000, as designated by the Bureau of the Census.
   b. **Small Urban Areas.** Those areas with a population greater than 5,000 and not within any Urbanized Areas.
   c. **Transitional Areas.** Those areas providing connections between urban and rural areas.
2. **Rural Areas.** Those places outside the boundaries of urban areas.

Topography that introduces horizontal and/or vertical constraints along a road segment, at more than one location, will establish the appropriate type of terrain for the design team to consider.

The topography of the land has an influence on the alignment of the roadway. To determine the type of terrain, the following descriptions are used:

1. **Level Terrain:** The available stopping sight distances are generally long or can be made to be so without construction difficulty or major expense.
2. **Rolling Terrain:** The natural slopes consistently fall below and rise above the roadway and occasional steep slopes offer some restriction to horizontal and vertical alignment.
3. **Mountainous Terrain:** Longitudinal and transverse changes in elevation are abrupt and extensive grading is frequently needed to obtain acceptable alignments.

2.2 HIGHWAY SYSTEMS

This section provides an overview of the highway systems within MDT. The functional classification system provides an overview of the types of roadway facilities that exist within MDT and the characteristics of the facilities. Other project context considerations are outlined to provide the design team with a fundamental understanding of how the functional classification may impact design controls and criteria. Additional information regarding the Federal-Aid System is provided in Section 2.2.3.

2.2.1 Functional Classification System

The functional classification of a highway is determined by the character of service it provides. Functional classification recognizes that the public highway network in Montana serves two basic and often conflicting functions: travel mobility and access to property. As shown in Exhibit 2-1, each type of highway or street may provide varying levels of access and mobility, depending upon its intended service. In the functional classification system, the overall objective is that the highway system, when viewed in its entirety, will yield an optimum balance between its access and mobility purposes.

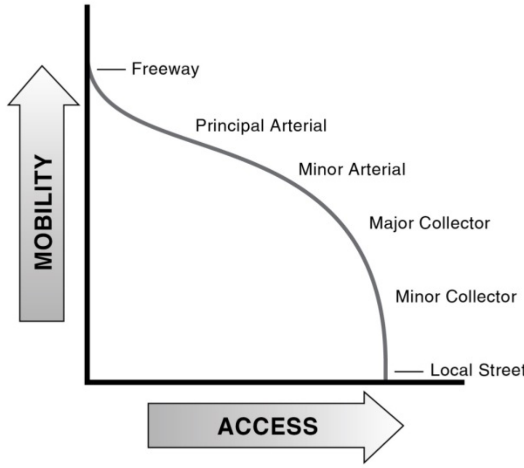


Exhibit 2-1
Functional Classification Mobility and Access

The overall objective is that the highway system will yield an optimum balance between its access and mobility purposes.

The functional classification system provides the guidelines for determining the geometric design of individual highways and streets. Once the function of the highway facility is defined, the design team can select an appropriate design speed, roadway width, roadside safety elements, amenities and other design values. The *RDM* is based upon this systematic concept to determining geometric design.

The functional classification map for State highways in Montana is provided at the following link on the Montana State Official Website.

MDT Functional Classification Map

For the purpose of the *RDM,* the functional classification for MDT facilities is consistent with the classifications described in the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets (Green Book) (2)*. The roadways that create the functional transportation system are different depending on whether it is in an urban or rural area. The following section provides a description for each functional class and the different characteristics for each type of area.

2.2.1.1 Freeways

Freeways, which include Interstate highways, are the highest level of arterial. These facilities are characterized by full control of access, high design speeds, and a high level of driver comfort and safety. For these reasons, freeways are considered a special type of highway within the functional classification system, and separate geometric design criteria have been developed for these facilities. Unless otherwise noted, Interstate System projects will be designed according to freeway design criteria.

2.2.1.2 Arterials

Arterials are characterized by a capacity to move relatively large volumes of traffic while also serving adjacent properties. The arterial system typically provides for higher travel speeds and serves longer trip movements. The arterial functional class is subdivided into principal and minor categories for rural and urban areas:

1. **Principal Arterials**. In both rural and urban areas, the principal arterials serve the highest traffic volumes and the greatest trip lengths. These facilities may be two or more lanes in each direction, with or without a median. In some cases, the level of geometric design is equivalent to that of freeways.
2. **Minor Arterials**. In rural areas, minor arterials will provide a mix of interstate and interregional travel service. In urban areas, minor arterials may carry local bus routes and provide intra-community connections. When compared to the principal arterial system, the minor arterials accommodate shorter trip lengths and lower traffic volumes, while providing more access to property.

2.2.1.3 Collectors

Collector routes are characterized by a roughly even distribution of their access and mobility functions. Traffic volumes will typically be somewhat lower than those of arterials. In rural areas, collectors serve intraregional needs and provide connections to the arterial system. In urban areas, collectors act as intermediate links between the arterial system and points of origin and destination. Urban collectors typically penetrate residential neighborhoods and commercial/industrial areas. Local bus routes will often include collector streets. Collectors are further described with the following subcategories.

1. **Major Collectors** serve traffic generators that are not served by the higher arterial system. This could include schools, freight distribution areas, parks or other agricultural areas. Major collectors link these types of areas to routes of higher classification, such as arterials.
2. **Minor Collectors** provide links to local traffic generators within rural and urban areas. These types of routes may be spaced consistently to accumulate traffic from local roads and bring developed areas to other collector roadways.

2.2.1.4 Local Roads and Streets

All public roads and streets not classified as freeways, arterials, or collectors are classified as local roads and streets. Local roads and streets are characterized by their many points of direct access to adjacent properties and their relatively minor value in accommodating mobility. Speeds and volumes are usually low and trip distances short. Through traffic is often deliberately discouraged.

2.2.2 Project Context and Functional Classification Considerations

There are additional project context and functional classification considerations that may impact the design controls and criteria. Understanding the project context can help the design team make appropriate design decisions that are consistent with the desired outcomes of a design project. The following subsections provide additional information on project context that the design team may consider.

Considerations for understanding the project context may include:

- **Rural or urban**
- **Project setting**
- **Roadway jurisdiction**
- **Existing or future constraints**
- **Overall roadway network**
- **Defining geometrics**
- **Current performance**

2.2.2.1 Future Land Use Needs

Understanding the anticipated land use needs in the vicinity of the roadway can help the design team consider the long-term vision and purpose for the roadway. For example, a roadway may have adjacent undeveloped land for the majority of its length, but the type of zoning may allow for more density and the need for access and multi-modal facilities (pedestrian, bicycle, and transit).

2.2.2.2 Coordination with Local Agencies

A project including local roadways or adjacent to a local community may consider how project context perspectives from local agencies can be integrated into the alternatives and design solutions. Local agencies may have developed separate categories or functional classes for local roadways that are different from the state functional classification system. The design team should consider how a roadway may function within a local community and coordinate with the local agencies to gain a full understanding of the roadway characteristics. As described in the *MDT Context Sensitive Solutions Guide (MDT CSS Guide)*, projects should involve local government and citizens to begin to ensure the needs of all interested parties are heard and considered throughout the project decision process. As described in that guide, a community-integrated approach can help guide future planning, funding and decision-making for the local and statewide transportation system, while meeting MDT's mission to emphasize quality, safety, cost effectiveness, economic vitality, and sensitivity to the environment *(3)*. This is also consistent with the performance-based approach described in Chapter 1, Section 1.2. Integrating stakeholders early in the project to help establish project context can help guide design decisions throughout the entire project.

2.2.2.3 Accommodating Other Modes of Travel

In some cases, the primary functional classification of a roadway should be considered along with other users of the roadway facility. Roadway facilities that accommodate several modes of travel, such as bicycles, pedestrians, railroads, and overweight/oversized vehicles, may require additional coordination and design considerations. Scenic byways also require special design consideration to serve the users and their needs.

2.2.3 Federal-Aid System

The Federal-aid system consists of those routes within Montana which are eligible for the categorical Federal highway funds. MDT, working with the local governments and in cooperation with the Federal Highway Administration (FHWA), has designated the eligible routes. United States Code, Title 23, describes the applicable Federal criteria for establishing the Federal-aid system.

2.2.3.1 National Highway System

The National Highway System (NHS) is a system of those highways determined to have the greatest national importance to transportation, commerce and defense in the United States. It consists of the Interstate Highway System, logical additions to the Interstate system, selected other principal arterials, and other roadway facilities which meet the requirements of one of the subsystems within the NHS. A map of the NHS in Montana is shown at the following link on the Montana Official State Website:

MDT National Highway System Map

To properly manage the NHS, the FHWA has mandated that each State highway agency develop and implement several management systems for those roadway facilities on the NHS. These include management systems for pavements, bridges, traffic monitoring, congestion and safety.

2.2.3.2 Surface Transportation Program (Non-NHS Routes)

The primary system includes Non-NHS rural minor arterials. The secondary system includes Non-NHS rural major collectors. The urban system includes both minor arterials and major collectors within urban boundaries.

The Surface Transportation Program (STP) refers to all Non-NHS routes and is a block-grant program which provides Federal-aid funds for any public road not functionally classified as a minor rural collector, or a local road or street. The STP replaced a portion of the former Federal-aid primary system and replaced all of the former Federal-aid secondary and urban systems, and it includes some collector routes, which were not previously on any Federal-aid system. Collectively, these are called Federal-aid routes. In addition, bridge projects using STP funds are not restricted to Federal-aid routes, but may be used on any public road. Transit capital projects are also eligible under the STP program. The basic objective of the STP is to provide Federal funds for improvements to roadway facilities not considered to have significant national importance with a minimum of Federal requirements for funding eligibility.

The primary system includes Non-NHS rural minor arterials. The secondary system includes Non-NHS rural major collectors. The urban system includes both minor arterials and major collectors within urban boundaries. These systems are also included in the NHS map described above. Some MDT facilities may be distinguished differently than the systems described above. The design team should refer to the MDT Functional Classification Map to identify the appropriate roadway category that will guide the design criteria.

2.2.3.3 Bridge Replacement and Rehabilitation Program

The Bridge Replacement and Rehabilitation Program (BRRP) has its own separate identity within the Federal-aid program. BRRP funds are eligible for work on any bridge on a public road regardless of its functional classification.

2.2.3.4 National Network (for Trucks)

The Surface Transportation Assistance Act (STAA) of 1982 required that the U.S. Secretary of Transportation, in cooperation with the State highway agencies, designate a national network of highways that allow the passage of trucks of specified minimum dimensions and weight. The objective of the STAA is to promote uniformity throughout the nation for legal truck sizes and weights on a National Network. The National Network includes all Interstate highways and significant portions of the former Federal-aid primary system (before the 1991 Intermodal Surface Transportation Efficiency Act) built to accommodate large-truck travel. In addition, the STAA requires that "reasonable access" be provided along other routes for the STAA commercial vehicles from the National Network to terminals and to facilities for food, fuel, repair and rest. In addition, access should be provided for household goods carriers, to points of loading and unloading.

In Montana, the National Network includes the Interstate highway system and all primary routes that existed prior to the Intermodal Surface Transportation Efficiency Act (ISTEA). The WB-67 (a 73-foot tractor-trailer combination truck) is allowed on all public roads in the State without a permit. The WB-100 (a 105-foot triple semitrailer) is only allowed on the Interstate system and for reasonable access to the system. MDT has defined "reasonable access" as 1 mile from any interchange on the Interstate system.

2.2.3.5 Frontage Roads

Although frontage roads are not on the Federal-aid system, they are the State’s responsibility. They are eligible for STP funds, as well as for Interstate Maintenance (IM) Program or National Highway (NH) funds if they are adjacent to an Interstate or NH route and are functionally classified as a major collector or above.

Frontage roads distribute and collect traffic and as such can be an essential element of a controlled access facility. Frontage roads enhance the safety of a controlled access facility by reducing the number of interchanges needed. They may also help to segregate lower speed local traffic from higher speed through traffic. They can also be used as an alternative system in case of freeway disruption.

2.3 PROJECT SCOPE

The project scope of work will reflect the basic intent of the roadway project and will determine the overall level of roadway improvement.

The project scope of work will reflect the basic intent of the roadway project and will determine the overall level of roadway improvement, to meet the purpose and need identified. Additional information can be found in the *Guidelines for Nomination and Development of Pavement Projects (4),* which is provided on the MDT Website at the following link:

<u>Guidelines for Nomination and Development of Pavement Projects</u>

1. **New Construction.** New construction is defined as horizontal and vertical alignment on a new location.
2. **Reconstruction**. Reconstruction is defined as work which includes one or more of the following:
    a. Full-depth pavement reconstruction for more than 50-percent of the project length;
    b. Intermittent reconstruction of the existing horizontal and vertical alignment for more than 25-percent of the project length; and/or
    c. Addition or removal of through travel lanes.
3. **Rehabilitation.** Rehabilitation is defined as work primarily intended to extend the service life of the existing roadway by making cost-effective improvements to upgrade the roadway. It may include full-depth pavement reconstruction for up to 50-percent of the project length and may include horizontal and vertical alignment revisions for up to 25-percent of the project length. Rehabilitation projects may be further categorized into major and minor rehabilitation projects.
    a. **Major Rehabilitation – with added capacity.** The intent of these projects is to rehabilitate the existing pavement structure through an engineered approach that considers the observed pavement distress, the in-place material, and roadway geometrics. Milling operations may be greater than 0.2 feet in depth and may expose base gravel, which can then be treated or modified. The work may include the addition of lanes or dualization of the existing highway (conversion from a two-lane highway to a divided multilane highway). New right-of-way and utility relocation may be required to improve geometrics, flatten slopes, or enhance safety. Other surfacing improvements shall follow the *Guidelines for Nomination and Development of Pavement Projects (4)*. The focus of this treatment is to extend the life of the pavement, improve ride quality, and/or add capacity. It may include rebuilding substandard horizontal or vertical curves, but the majority of the work shall be primarily on the existing alignment. It typically requires rebuilding less than 25-percent of the total project length. It may also include widening the lanes or shoulders. This work could also include base course improvement and removal of poor or contaminated material. Other improvements such as guardrail and/or other safety improvements as outlined in the *Guidelines for Nomination and Development of Pavement Projects* may be included.

b. **Major Rehabilitation – without added capacity.** The intent of these projects is to rehabilitate the existing pavement through an engineered approach that considers observed pavement distress, the in-place material, and roadway geometrics. Milling operations may be greater than 0.2 feet in depth and may expose base gravel, which can then be treated or modified. New right-of-way and utility relocation may be required to improve geometrics, flatten slopes, or enhance safety. Other surfacing improvements shall follow the *Guidelines for Nomination and Development of Pavement Projects (4)*.

The focus of this treatment is to expand the life of the pavement and improve ride quality. It may include rebuilding substandard horizontal or vertical curves, but the majority of the work shall be on existing alignment. It typically requires rebuilding less than 25-percent of the total project length. It may include widening the lanes or shoulders without adding more through lanes. This work could also include base course improvement and removal of poor or contaminated material. Other improvements such as guardrail and other safety improvements as outlined in the *Guidelines for Nomination and Development of Pavement Projects* may be included (4).

c. **Minor Rehabilitation.** The intent of these projects is to rehabilitate the existing pavement surface through an engineered approach that considers the observed pavement distress and in-place materials. Milling operations will be less than or equal to 0.3 feet in depth without exposing base gravel. All slope work and other features are usually accomplished within existing right-of-way. Other surfacing improvements shall follow the *Guidelines for Nomination and Development of Pavement Projects (4)*.

The objective of this treatment is to extend the life of the pavement structure by rehabilitating the wearing surface only. Other improvements such as slope flattening, guardrail and and/or other safety improvement as outlined in the *Guidelines for Nomination and Development of Pavement Projects* may be included *(4)*.

4. **Pavement Preservation.** Pavement Preservation is a type of preventative maintenance that includes such treatments as crack seal, seal and cover, milling less than or equal to 0.2 feet, and overlays less than or equal to 0.2 feet (the overlay thickness can be increased to a total of 0.22 feet inches, if an isolation lift is needed to address heavy crack sealing of the existing surfacing). For more complete information on pavement preservation projects, refer to the *Guidelines for Nomination and Development of Pavement Projects (4)*. Additional information on preservation projects including roadside safety treatments, such as guardrail treatments, is provided in Chapter 9.

Scheduled maintenance is a type of preventative maintenance that is intended to extend the useful life of pavement through scheduled projects. This may include work on roadway surfaces in advance of various levels of observable deterioration.

5. **Other Projects**. This would include projects such as spot safety improvements, structure rehabilitation, sidewalks, and wetland mitigation.

2.3.1 Accessibility Considerations

To understand the accessibility needs, the design team should consider the land use area and the characteristics of the roadway.

Projects should consider accessibility for all users. To understand the accessibility needs, the design team should consider the land use area, such as rural and urban and the characteristics of the roadway facility, such as the existing and future anticipated level of pedestrian and bicycle activity. For New Construction projects, the new roadway should include appropriate pedestrian and bicycle accommodations. For Rehabilitation projects, the accessibility considerations may be determined by whether the project includes major or minor rehabilitation. The design team may need to determine the level of impact to any existing pedestrian and bicycle facilities, or determine whether an existing roadway or intersection needs to be upgraded to provide additional pedestrian and bicycle features. For Pavement Preservation projects, accessibility considerations must be addressed where pedestrian facilities are added or existing pedestrian facilities are altered. The design team should reference the *Public Right-of-Way Accessibility Guidelines (PROWAG)* and the *Department of Justice/Department of Transportation Joint Technical Assistance on the Title II of the Americans with Disabilities Act Requirements to Provide Curb Ramps when Streets, Roads, or Highways are Altered through Resurfacing* for additional information on accessibility considerations *(5, 6)*. The Department of Justice Joint Technical Assistance is provided on the MDT Website at the following link:

Department of Justice/Department of Transportation Joint Technical Assistance on the Title II of the Americans with Disabilities Act Requirements to Provide Curb Ramps when Streets, Roads, or Highways are Altered through Resurfacing.

2.4 ROUTE SEGMENT PLAN

The Route Segment Plan is based on functional classification, traffic volumes, route continuity and is part of the *MDT Geometric Design Standards (1)*. The purpose is to identify and define a consistent pavement width to be used when reconstruction or major widening is conducted on a route segment. For NHS roadways, the standards provided in the AASHTO *Green Book* set the minimum standards. The MDT Route Segment Plan Map is provided at the following link on the MDT Website.

MDT Route Segment Plan Map

The MDT Roadway Width Decision Process can be found at the following link on the MDT Website.

MDT Roadway Width Decision Process (under construction)

Chapter 5 provides additional information regarding the roadway width decision process for MDT. Additional roadway width design information for various types of roadways can be found in the *AASHTO Green Book* and the *Guidelines for Nomination and Development of Pavement Projects (2, 4)*.

2.5 SPEED

Design speed is a selected speed used to determine the various geometric design features of the roadway. It should be appropriate with respect to topography, anticipated operating speeds, adjacent land use and functional classification of the roadway. The selected design speed for each project will establish criteria for several design elements, including horizontal and vertical curvature, superelevation, and sight distance. The speed relates to the driver's comfort and expectation, rather than the speed at which a vehicle will lose control. The following section discusses the selection of design speed, and the MDT *Geometric Design Standards* presents specific design speed criteria for various conditions *(1).*

Design speed should consider topography, anticipated operating speeds, adjacent land use and functional classification of the roadway.

The 85th-percentile speed is the speed at or below which 85-percent of vehicles travel on a given roadway. Nationally, the most common application of the value is its use as one of the factors for determining the posted, legal speed limit of a roadway section when not set by state statute. In most cases, field measurements for the 85th-percentile speed will be conducted during off-peak hours when drivers are free to select their desired speed.

When the posted speed limit is based on a traffic engineering study, the following are considered:

1. The 85th-percentile speed;
2. Pace, which is the 10 miles per hour (mph) range of speeds in which the highest number of speed observations are recorded;
3. Speed profile;
4. Montana Code *(7)*;
5. Type and density of roadside development;
6. Functional classification, land use and terrain;
7. Speeds on adjacent sections of the same roadway;
8. The crash experience for the previous three to five years, at least;
9. Road surface characteristics, shoulder condition, grade, alignment, and sight distance; and
10. Parking practices and pedestrian activity.

Additional guidance on selecting posted speed limits is provided by the Traffic and Safety Bureau.

2.5.1 Design Speed Selection

The selection of a design speed for a project should consider all of the following:

1. **Functional Classification**. In general, the higher class roadway facilities are designed with a higher design speed than the lower class facilities.
2. **Urban/Rural**. Design speeds in rural areas are generally higher than those in urban areas. This is consistent with the typically fewer constraints in rural areas (e.g., less development).

3. **Terrain.** Typically, the flatter the terrain, the higher the selected design speed will be. This is consistent with the typically higher construction costs associated with more rugged terrain. In certain situations, especially where a road follows a river through rugged terrain, the vertical alignment will be relatively level. However, the flat vertical alignment is achieved through the use of smaller radii horizontal curves. The utilization of flatter horizontal curves would result in extensive grading. For these situations, the lower design speed associated with more rugged terrain is appropriate.
4. **Driver Expectancy**. The selected design speed should be consistent with driver expectancy. The design team should consider the following when selecting a design speed:
   a. Avoid major changes in the design speed throughout the project limits and provide incremental speed reduction, where necessary;
   b. Avoid placing minimum radius horizontal curves at the end of long tangents;
   c. Consider the expected posted speed in the selection of the design speed, including an evaluation of 85th-percentile speed; and
   d. Balance the horizontal and vertical alignment (e.g., curvilinear alignment used with rolling grades).
5. **Project Context.** The selected design speed should be consistent with the project context, taking into account multimodal user considerations, adjacent land uses, roadway environment, and overall project setting.

For geometric design application, the relationship between the design elements and the selected design speed reflects the importance of addressing the safety and operational needs for the roadway. The value of a transportation facility in carrying goods and people is judged by its convenience and economy, which are directly related to its speed. The MDT *Geometric Design Standards* presents specific design speed criteria for various conditions *(1).*

2.6 TRAFFIC VOLUME CONTROLS

Traffic volume is a primary design control that can influence geometric element dimensions or considerations for a design project.

Traffic volume is a primary design control that can influence geometric element dimensions or considerations for a design project. The following traffic volume terminology is used throughout this discussion:

1. **Annual Average Daily Traffic (AADT).** The total yearly traffic volume in both directions of travel divided by the number of days in a year.
2. **Average Daily Traffic (ADT).** The total traffic volume in both directions of travel during a time period greater than one day but less than one year divided by the number of days in that time period.
3. **Capacity.** The maximum number of vehicles which reasonably can be expected to traverse a point or uniform roadway section during a given time period under prevailing roadway, traffic, and control conditions.
4. **Design Hourly Volume (DHV).** The one-hour vehicular volume in both directions of travel in the design year selected for roadway design. The DHV is typically the 30th highest hourly volume during the design year.

5. **Equivalent Single-Axle Loads (ESALs).** The summation of equivalent 18,000 pound single-axle loads used to convert mixed traffic to design traffic for the design period.
6. **Level of Service (LOS).** A qualitative concept which has been developed to characterize a traveler's perception of quality of service. In the *Highway Capacity Manual (HCM)*, the qualitative grades for each level of service (A through F) have been assigned to quantitative measures for each highway element, including *(8):*
   a. freeway mainline;
   b. freeway mainline/ramp junctions;
   c. freeway weaving areas;
   d. interchange ramps;
   e. two-lane, two-way rural highways;
   f. multilane rural highways;
   g. signalized intersections;
   h. unsignalized intersections; and
   i. urban streets.

Appendix E presents guidelines for selecting the level of service for capacity analyses in road design.

2.6.1 Design Year Selection

2.6.1.1 Traffic Volumes

A roadway should be designed to accommodate the traffic volume expected to occur within the life of the roadway under reasonable maintenance. This involves projecting the traffic conditions for a selected future year. The following will apply:

1. **New Construction/Reconstruction Projects and Rehabilitation**. The roadway design will be based on a 20-year projection of traffic volumes. Life-cycle analysis for pavement types may exceed this period. For roads on the secondary system (refer to Section 2.2.3.2 for definition), the selection of certain geometric features is based on the current traffic volumes.
2. **Pavement Preservation**. For these projects, the pavement surfacing is typically non-engineered and is based on an 8-year minimum design forecast year. However, any traffic operations assessments will be based on a 20-year traffic projection.

The design team may consider interim design years and use a performance-based road design approach to understand the tradeoffs of the design year selection.

Future traffic volumes on MDT roadway facilities are provided by the MDT Data and Statistics Bureau. The design year is measured from the expected construction completion date. The design team should understand the tradeoffs for designing a roadway to accommodate traffic volumes for a specific design year. A performance-based design approach may define an intended project outcome that will provide benefits to the transportation system on an interim basis under the specific project context. This could result in a design year that is different than the typical 20-year projection.

2.6.1.2 Other Highway Elements

The following presents the recommended criteria for consideration of a design year for highway elements other than road design:

1. **Bridges/Underpasses**. The structural life of a bridge may be 75 years or more. For new bridges (including bridge replacements), the initial clear roadway width of the bridge or underpass will be based on the 20-year traffic volume projection beyond the construction completion date for flexible pavement designs and 30 years for concrete pavements. See the *MDT Structures Manual* for more information *(9).* Additional design standards for bridges are provided at the following link on the MDT Website:

   Bridge Design Standards

2. **Drainage Design.** Drainage appurtenances are designed to accommodate a flow rate based on a specific design year (or frequency of occurrence). The selected design year or frequency will be based on the functional class of the roadway and the specific drainage appurtenance (e.g., culvert). New drainage facilities are designed to have a structural life of 75 years. The MDT Hydraulics Section is responsible for determining the criteria for selecting a design year for drainage. Additional drainage design information is provided in Chapter 11.
3. **Pavement Design.** The pavement structure is designed to withstand the vehicular loads it will sustain during the design analysis period. The MDT Materials Bureau is responsible for determining criteria for selecting a design year for pavement design. Preventative maintenance overlays (pavement preservation projects) are utilized to extend the life of the riding surface and are not designed for a specific vehicular loading or analysis period.

2.6.2 Design Hourly Volumes

For most geometric design elements which are impacted by traffic volumes, the peaking characteristics are most significant. The roadway facility should be able to accommodate the design hourly volume at the selected level of service. This design hourly volume (DHV) will affect many design elements including the number of travel lanes, lane and shoulder widths and intersection geometrics. However, the performance-based design approach takes into account tradeoffs and the intended project outcome may focus on safety, accessibility or other performance measures other than capacity. Such a project may consider design hour volumes that are derived based on the overall project needs and context.

2.6.3 Traffic Operations Analysis

The objective of conducting traffic operations analysis is to design the roadway mainline or intersection to accommodate the selected design hourly volume (DHV) at the selected level of service (LOS). LOS Criteria for various types of roadway facilities is provided in Appendix E. The detailed calculations, highway factors and methodologies are presented in the *Highway Capacity Manual* (*HCM*) *(8).* During the analysis, the design service volume (or flow rate) of the facility is calculated.

The MDT Traffic and Safety Bureau is responsible for performing all capacity analyses required for the project.

For various types of highway facilities, the *HCM* documents the measures of effectiveness that should be used in capacity analyses to determine level of service. For each facility type, the *HCM* provides the analytical tools necessary to calculate the numerical value of its respective measure of effectiveness.

The following presents the simplified procedure for conducting a capacity analysis for the roadway mainline:

1. Select the design year.
2. Determine the DHV.
3. Select the target level of service.
4. Identify and document the proposed roadway geometric design (lane width, clearance to obstructions, number and width of approach lanes at intersections, etc.).
5. Using the *HCM*, analyze the capacity of the highway element for the proposed design.
6. Compare the calculated service flow rate to the DHV.

Coordinate with the MDT Traffic and Safety Bureau for additional information on level of service criteria.

The default values in the *HCM* will apply unless reliable local data is available. The level of service targets for various roadway facilities are provided in Appendix E.

2.7 ACCESS CONTROL

The density and number of access points along a roadway segment can impact mobility and safety. Access control considerations for private and public access can affect the road design process and design elements. Private access control consists of approaches, such as a driveway, between private landowners and public MDT facilities. Public access control (MDT facilities, and/or local agencies' roads) relates to intersection spacing along MDT facilities. The following sections provide an overview of these types of access control.

2.7.1 Private Access Control

Private access control is defined as the condition where the public authority fully or partially controls the right of abutting owners to have access to and from the public roadway. Private access control may be exercised by statute, zoning, right-of-way purchases, approach controls and permits, turning and parking regulations or geometric design (e.g., approach spacing).

Additional access control information is provided in the *MDT Approach Manual for Landowners and Developers*, located at the following link on the MDT Website.

MDT Approach Manual for Landowners and Developers

The following provides definitions for the three basic types of access control:

1. **Full Control (Access Controlled).** Full control of access is achieved by giving priority to through traffic by providing access only at grade separation interchanges with selected public roads. No at-grade crossings or approaches are allowed. The freeway is the common term used for this type of highway. Full control of access maximizes the capacity, safety, and vehicular speeds on the freeway.
2. **Limited Access Control.** Limited access control is an intermediate level between full control and regulated access. Priority is given to through traffic, but a few at-grade intersections and approaches may be allowed. Limited access control on a specific highway is established by passage of an Access Control Resolution by the Transportation Commission. The proper selection and spacing of at-grade intersections and service connections will provide a balance between the mobility, safety and access service of the highway.
3. **Regulated Access.** All highways warrant some degree of access control by permit or by design. Access is regulated through the granting of revocable permits for the construction and maintenance of approaches. If access points to other public roads and approaches are properly spaced and designed, the adverse effects on highway capacity and safety will be minimized. These points should be located where they can best suit the traffic and land use characteristics of the highway under design. Their design should enable vehicles to enter and exit safely with a minimum of interference to through traffic.

Limited access control and regulated access is exercised by MDT on the State highway system (see the *MDT Approach Manual for Landowners and Developers* described above) and by the local jurisdiction on other facilities to determine where private interests may have access to and from the public road system.

Coordinate with the Traffic and Safety Bureau and Right-of-Way Bureau for additional information on intersections and access spacing.

2.7.2 Public Access

To provide a safe and efficient transportation system, MDT maintains public access control procedures and criteria to govern roadway approaches, access control, spacing standards, medians and restriction of turning movements in compliance with statewide planning goals. Local agencies will collaborate with MDT when considering new public intersections to provide appropriate intersection spacing.

2.8 SIGHT DISTANCE

Designing a roadway with adequate sight distance allows vehicles to travel safely and efficiently and perform necessary driving maneuvers. This section provides an overview of the various types of sight distance evaluated in road design. Descriptions and criteria tables for each type of sight distance are provided in this section. Detailed equations and examples for calculating sight distance are provided in Appendix K. The discussions in this chapter relate to design elements discussed in other *RDM* chapters; therefore, references for additional design considerations are provided throughout the following subsections. The following types of sight distance will be discussed:

1. Stopping Sight Distance
    a. Horizontal Sight Distance
    b. Vertical Sight Distance
2. Intersection Sight Distance
3. Passing Sight Distance
4. Decision Sight Distance

Graphical sight distance representations should be reviewed to further understand if the calculated criteria are consistent with project context.

The following sections provide sight distance equations and criteria tables to assist the design team in evaluating this design element during a project. As the design team evaluates the sight distance criteria, graphical representation of sight lines and distances for existing conditions and future conditions should be reviewed to further understand if the calculated criteria are consistent with project context and local conditions.

2.8.1 Stopping Sight Distance

Stopping sight distance (SSD) is the sum of the distance traveled during a driver's perception/reaction or brake reaction time and the distance traveled while braking to a stop, as shown in Equation 2.8-1. SSD is a controlling criterion that should be carefully evaluated during a design project. The *MDT Geometric Design Standards* provide additional information on the SSD criteria for MDT roadway facilities *(1).*

$$SSD = Brake\ Reaction\ Distance + Braking\ Distance$$

Equation 2.8-1

SSD is affected by the grade of the roadway. Vehicles traveling downhill will require more SSD than a vehicle traveling uphill on a roadway. Equation 2.8-2 provides stopping sight distances for passenger cars on a level grade and Exhibit 2-2 that summarizes the SSD for passenger cars on level grade. When applying the SSD values, the height of eye is assumed to be 3.5 feet, and the height of object 2.0 feet.

$$SSD_{Level} = 1.47Vt + 1.075\left(\frac{V^2}{a}\right)$$

Equation 2.8-2

where:

SSD = stopping sight distance, ft

V = design speed, mph

t = brake reaction time, 2.5 s

a = deceleration rate, 11.2 ft/s^2

Exhibit 2-2
Stopping Sight Distance on Level Roadways

Design Speed (V) (mph)	Brake Reaction Distance 1.47Vt (ft)	Braking Distance $1.075(V^2/a)$ (ft)	Calculated SSD (ft)	SSD Rounded for Design (ft)
15	55.1	21.6	76.7	80
20	73.5	38.4	111.9	115
25	91.9	60.0	151.9	155
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	165.4	194.4	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820
80	294.0	614.3	908.3	910

Brake Reaction Time (t) = 2.5 s; Deceleration Rate (a) = 11.2 ft/s^2

Equation 2.8-3 provides stopping sight distances for passenger cars on grades and Exhibit 2-3 that summarizes the SSD for passenger cars on various grades.

Equation 2.8-3

$$SSD_{Downgrades} = 1.47Vt + \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) - G\right]}$$

$$SSD_{Upgrades} = 1.47Vt + \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) + G\right]}$$

where:

SSD = stopping sight distance, ft
V = design speed, mph
t = brake reaction time, 2.5 s
a = deceleration rate, 11.2 ft/s^2
G = gradient, ft/ft

Exhibit 2-3
Stopping Sight Distance on Grades

Note: Refer to Equation 2.8-3 for calculating stopping sight distances for upgrades or downgrades other than those shown in Exhibit 2-3. Interpolation between the values shown is not appropriate. Additional equations and examples are also shown in Appendix K.

Design Speed (V) (mph)	Stopping Sight Distances (ft)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	190	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704
80	965	1035	1121	859	817	782

Brake Reaction Time (t) = 2.5 s; Deceleration Rate (a) = 11.2 ft/s^2

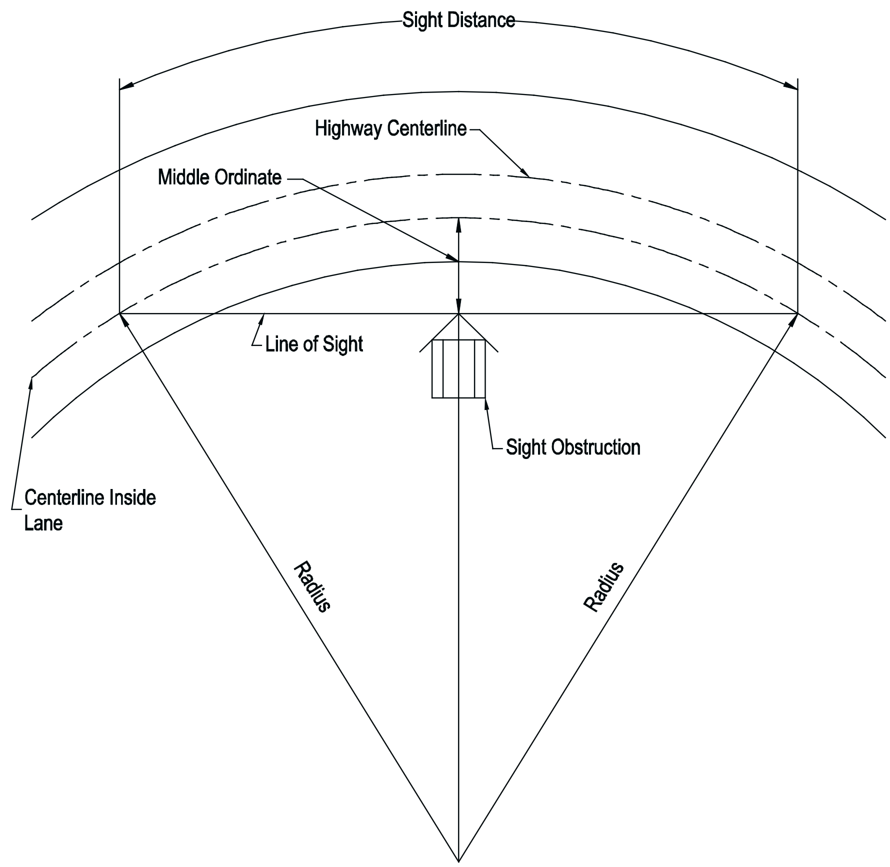
2.8.1.1 Horizontal Stopping Sight Distance

Sight obstructions on the inside of a horizontal curve are defined as obstacles which interfere with the line of sight on a continuous basis. These may include walls, cut slopes, wooded areas, buildings, and high farm crops. In general, point obstacles such as traffic signs and utility poles are not considered sight obstructions on the inside of horizontal curves. The design team must examine each curve individually to determine whether it is necessary to remove an obstruction or to adjust the horizontal alignment to obtain the required sight distance.

The design team must examine each curve individually to determine the need to remove an obstruction or to adjust the horizontal alignment.

Exhibit 2-4 illustrates the components for determining horizontal sight distance.

**Exhibit 2-4
Diagram Illustrating Components for Determining Horizontal Sight Distance**



Application

For application, the height of eye is 3.5 feet and the height of object is 2.0 feet. Both the eye and object are assumed to be in the center of the inside travel lane. In the elevation view, the line-of-sight intercept with the obstruction is at the midpoint of the sightline and 2.75 feet above the road surface at the center of the inside lane, for constant gradients.

2.8.1.1.1 Longitudinal Barriers

The design team should check the line of sight over a barrier along a horizontal curve and attempt to locate the barrier such that it does not block the line of sight.

Longitudinal barriers (e.g., bridge rails, guardrail, and concrete median barrier) can cause sight distance restrictions at horizontal curves, because barriers are placed relatively close to the traveled way (often 10 feet or less) and because their height is greater than 2 feet. The design team should check the line of sight over a barrier along a horizontal curve and attempt to locate the barrier such that it does not block the line of sight. The following should also be considered:

1. **Superelevation.** A superelevated roadway will elevate the driver eye and improve the line of sight over the barrier.
2. **Vertical Curves.** The line of sight over a barrier may be improved for a driver on a sag vertical curve and lessened on a crest vertical curve.

3. **Barrier Height.** The higher the barrier, the more obstructive it will be to the line of sight.
4. **Object Height.** Because of the typical heights of barriers, there may be many sites where the barrier blocks visibility to lower objects but does not block the view of taller objects. This observation provides some perspective to the potential safety problem at the site.

Each barrier location on a horizontal curve will require an individual analysis to determine its impacts on the line of sight. The design team must determine the elevation of the driver eye, the elevation of the object (2 feet above the pavement surface) and the elevation of the barrier where the line of sight intercepts the barrier run. If the barrier does block the line of sight to a 2-foot object, the design team should consider relocating the barrier or revising the horizontal alignment.

Additional horizontal curve information is provided in Chapter 3.

2.8.1.2 Vertical Curve Sight Distance

One of the design controls for vertical curves is the provision of adequate sight distances for vehicles traveling through sag and crest vertical curves at the designated design speed. It is recommended that all vertical curves are designed to provide at least the stopping sight distances shown in Exhibit 2-2 and additional stopping sight distance should be provided when practical. The following information provides equations and example exhibits for designing sag and crest vertical curves with adequate sight distance.

Additional SSD should be provided at intersections, if practical, especially if turn lanes are not provided.

2.8.1.2.1 Crest Vertical Curves

Determining the minimum length of a crest vertical curve using stopping sight distance criteria typically results in a curve that is satisfactory from a safety, comfort, and appearance standpoint. Exhibit 2-5 illustrates the design elements used in determining the length of a crest vertical curve to provide adequate sight distance. The assumed height of eye is 3.5 feet and height of object is 2.0 feet.

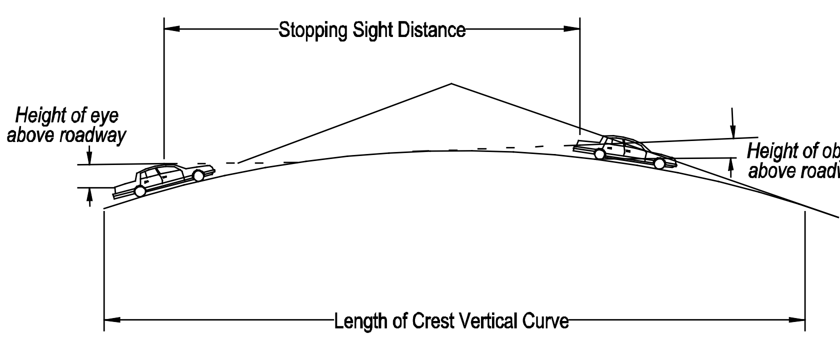


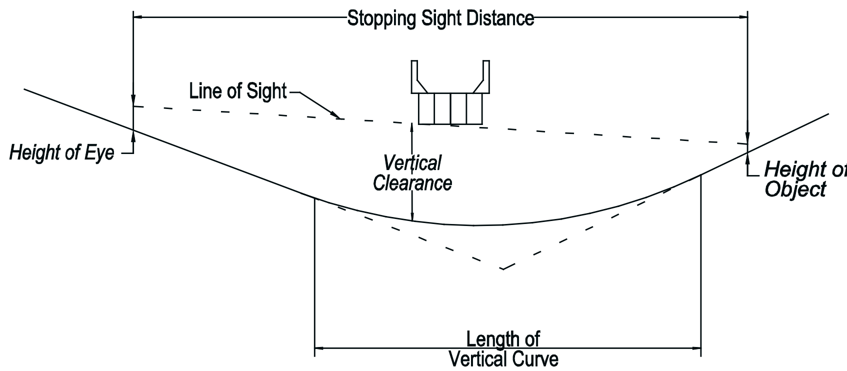
**Exhibit 2-5
Design Elements Considered for Crest Vertical Curves to Provide Sight Distance**

2.8.1.3 Sag Vertical Curves

Sag vertical curves are designed to allow the vehicular headlights to illuminate the roadway surface (i.e., the height of object is 0 feet) for a given sight distance. The length of the sag vertical curve will depend upon the difference between the two tangent grades for the specific curve and depend upon the selected sight distance and headlight height. The principal control in the design of sag vertical curves is to ensure that, at a minimum, stopping sight distance (SSD) is available for headlight illumination throughout the curve. The design assumes that there is a 1-degree upward divergence of the light beam from the longitudinal axis of the headlights.

Stopping sight distance for sag vertical curves at an undercrossing should also be considered. Sight distance on a roadway through a grade separation should be at least as long as the minimum stopping sight distance and where practical, even longer. Exhibit 2-6 illustrates the design components of designing a sag vertical curve at an undercrossing. The assumed height of eye is 8 feet for a truck driver and height of object is 2 feet for the taillights of a vehicle.

Exhibit 2-6
Sight Distance at an Undercrossing



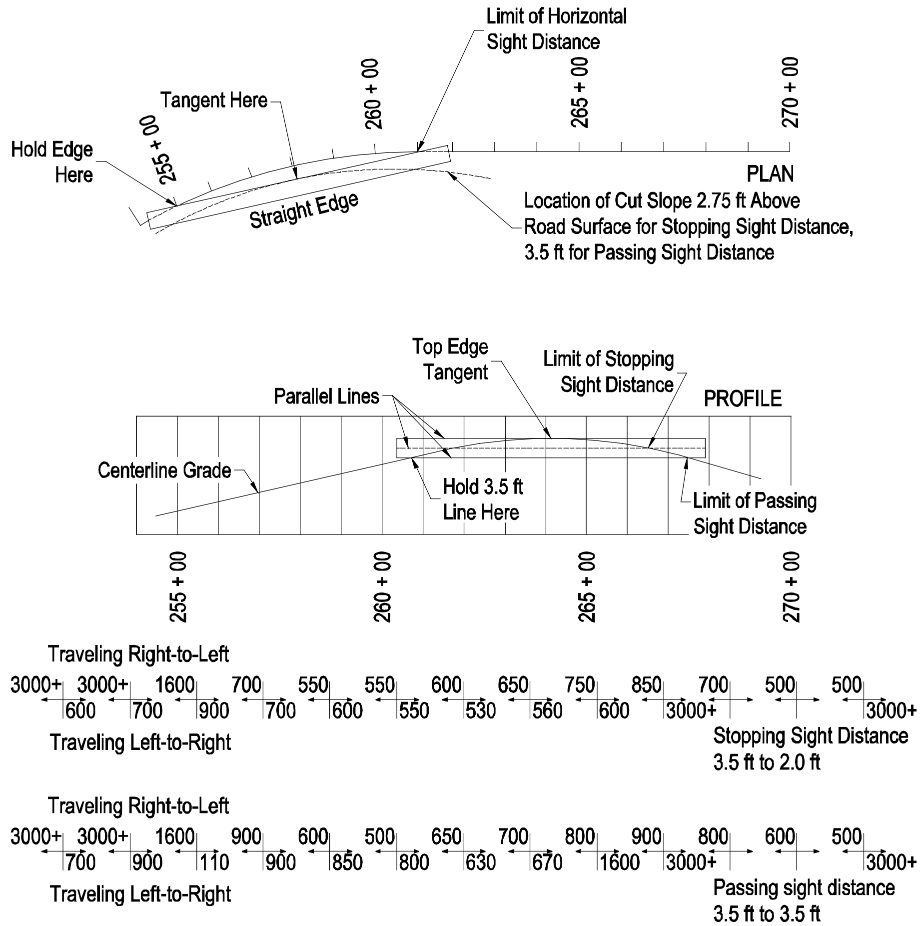
Additional sag vertical curve information is provided in Chapter 4.

2.8.1.4 Horizontal and Vertical Combinations

Sight distance should be considered early in the design process when the horizontal and vertical alignments are still able to be adjusted relatively easily. By evaluating the sight distance graphically on the design plans and recording the sight distance at frequent intervals, the design team can review the overall layout and produce a more balanced design. This may require minor adjustments to the plan and profile. A method for scaling sight distance on a design plan is shown in Exhibit 2-7. This exhibit shows the sight distance that may be recorded on the design plans.

The view of the roadway may change, therefore it is recommended that sight distance be measured and recorded for both directions of travel at each station on the design plans. This includes both horizontal and vertical sight distances being measured and the shorter of the lengths being recorded. Horizontal sight distance on the inside of a curve may be limited by obstructions, such as buildings, landscaping, cut sections or other topographic features. Horizontal sight distance is measured with a straight edge, as shown in Exhibit 2-7, and graphically shows the cut slope obstruction. Vertical sight distance may be scaled from a plotted profile, which is also shown in Exhibit 2-7.

Exhibit 2-7
Example of Scaling Sight Distance Method



Example Sight Distance Record

Exhibit 2-7 was developed from the AASHTO Green Book, Figure 3-2. This resource document provides additional information for the design team to reference, if needed *(2)*.

2.8.2 Intersection Sight Distance

For an at-grade intersection to operate properly, adequate sight distance should be available. Intersection sight distance (ISD) is a design element that should be evaluated during a design project to ensure the design meets MDT standards. Appendix F provides additional information on the SSD criteria for MDT roadway facilities.

The design team should provide appropriate sight distance for a driver to perceive potential conflicts and to perform the actions needed to negotiate the intersection safely. The additional costs and impacts of removing sight obstructions are often justified. If it is impractical to remove an obstruction blocking the sight distance, the design team should consider providing traffic control devices or design applications (e.g., warning signs or turn lanes) which may not otherwise be considered.

The design team should provide sufficient sight distance for a driver to perceive potential conflicts and to perform the actions needed to negotiate the intersection

In general, ISD refers to the corner sight distance available in intersection quadrants which allows a driver approaching an intersection to observe the actions of vehicles on the crossing leg(s). ISD evaluations involve establishing the needed sight triangle in each quadrant by determining the legs of the triangle on the two crossing roadways. The necessary clear sight triangle is based on the type of traffic control at the intersection and on the design speeds of the two roadways.

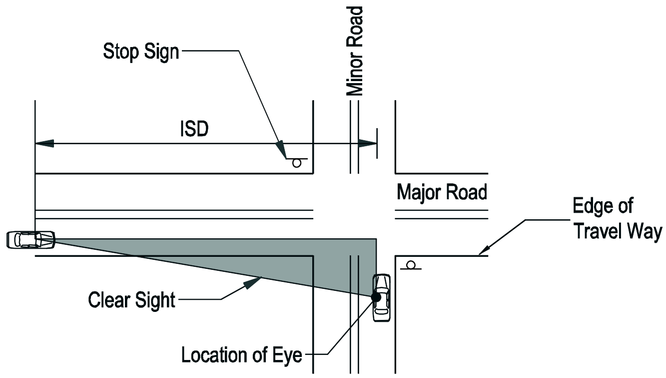
MDT uses gap acceptance as its basic methodology in the design of intersection sight distance. Additional information on gap acceptance is provided in the *AASHTO Green Book (2).*

There are specific design considerations, criteria and equations for each of the following types of traffic control:

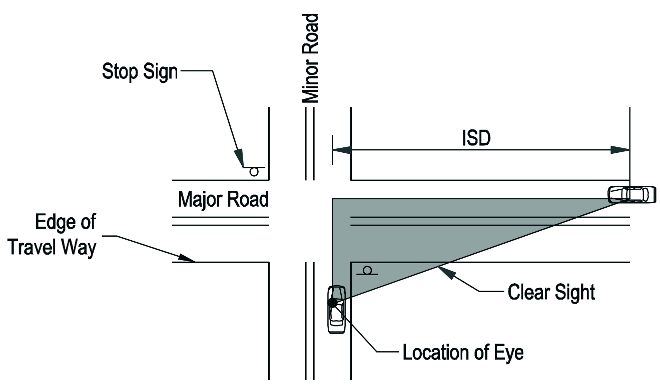
- **No Traffic Control (AASHTO Case A).** Intersections between low-volume and low-speed roads/streets may have no traffic control. At these intersections, appropriate corner sight distance should be available to allow approaching vehicles to adjust their speed to avoid a collision.
- **Stop Controlled/Traffic Signal Controlled** (AASHTO Case B and D). Where traffic on the minor road of an intersection is controlled by stop signs, the driver of the vehicle on the minor road must have appropriate sight distance for a safe departure from the stopped position assuming that the approaching vehicle comes into view as the stopped vehicle begins its departure. If a signalized intersection implements two-way flashing operations or right turns are permitted on red, the stop-controlled criteria may apply for intersection sight distance.

  MDT uses gap acceptance as the conceptual basis for its ISD criteria at stop-controlled and traffic-signal controlled intersections. The intersection sight distance is obtained by providing clear sight triangles both to the right and left. An example of this is shown in Exhibit 2-8.
- **Yield Control (AASHTO Case C).** At intersections controlled by a yield sign (except roundabouts, which are described below), drivers on the minor road will typically slow down as they approach the major road; make a stop/continue decision; and either brake to a stop or continue their crossing or turning maneuver onto the major road.
- **All-Way-Stop (AASHTO Case E).** At intersections with all-way stop control, provide appropriate sight distance so that the first stopped vehicle on each approach is visible to all other approaches.

Exhibit 2-8
Sight Lines for ISD at Stop Controlled and Traffic Signal Control



Clear Sight Triangle For Viewing



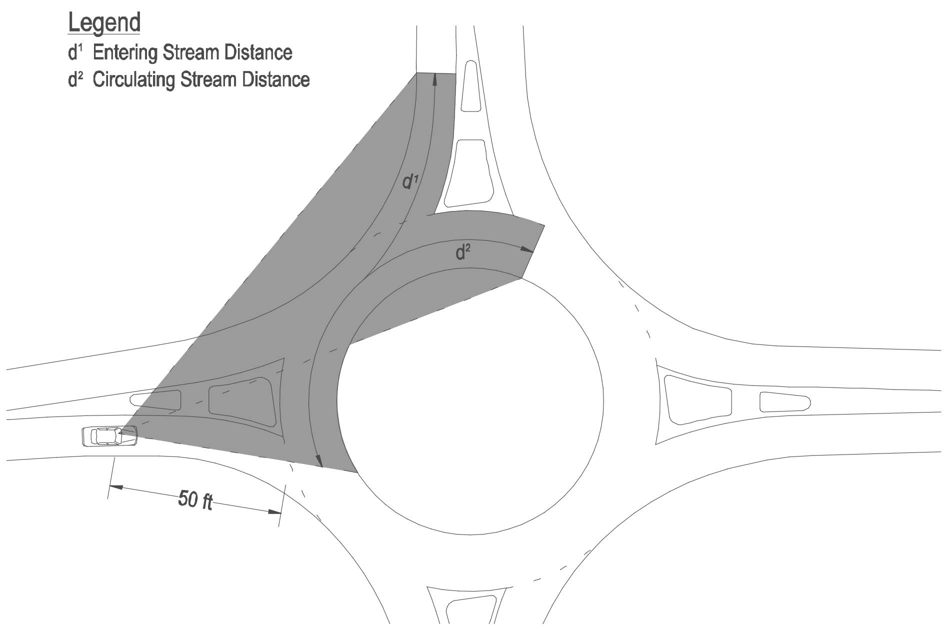
Clear Sight Triangle For Viewing

- **Stopped Vehicle Turning Left (AASHTO Case F).** At all intersections, regardless of the type of traffic control, the design team should consider the sight distance needs for a stopped vehicle turning left from the major road. The driver must see straight ahead for an appropriate distance to turn left and clear the opposing travel lanes before an approaching vehicle reaches the intersection. In general, if the major roadway has been designed to meet the stopping sight distance criteria, intersection sight distance will only be an issue where the major road is on a horizontal curve, where there is a median, or where there are opposing vehicles making left turns at the intersection.
- **Channelized Right-Turn.** When designing a channelized right-turn lane at an intersection, the sight distance for the approaching vehicles and sight distances for the pedestrians approaching the intersection should

be considered. Sight lines should be clear of obstructions and provide sufficient visibility for various users.

- **Roundabouts.** Intersection sight distance should be evaluated at the entries of a roundabout. At roundabouts, the sight triangle should follow the curvature of the roadway, and thus distances should be measured not as straight lines but as distances along the vehicular path. *NCHRP Report 672: Roundabouts An Information Guide, Second Edition* describes the method for evaluating intersection sight distance at roundabouts, *(10).* Exhibit 2-9 presents a diagram showing the method for determining intersection sight distance.

Exhibit 2-9
Intersection Sight Distance at Roundabouts



2.8.2.1 Measures to Improve Intersection Sight Distance

The available ISD should be checked using the above noted parameters. If the ISD values from the above sections are provided, no further investigation is needed. If the line of sight is restricted by either bridge railing, guardrail, other obstructions, or the horizontal and vertical alignment of the main road, and the ISD value is not available, evaluate one or more of the following modifications, or a combination, to achieve the intersection sight distance:

1. Remove the obstructions that are restricting the sight distance,
2. Relocate the intersecting road farther from the end of the bridge, if a bridge is present,
3. Widen the structure on the side where the railing is restricting the line of sight, if a bridge is present,
4. Flare the approach guardrail,
5. Revise the grades on the main road and/or the intersecting road,
6. Close the intersecting road,

7. Make the intersecting road one-way away from the main road, and/or
8. Review other measures that may be practical at a particular location.

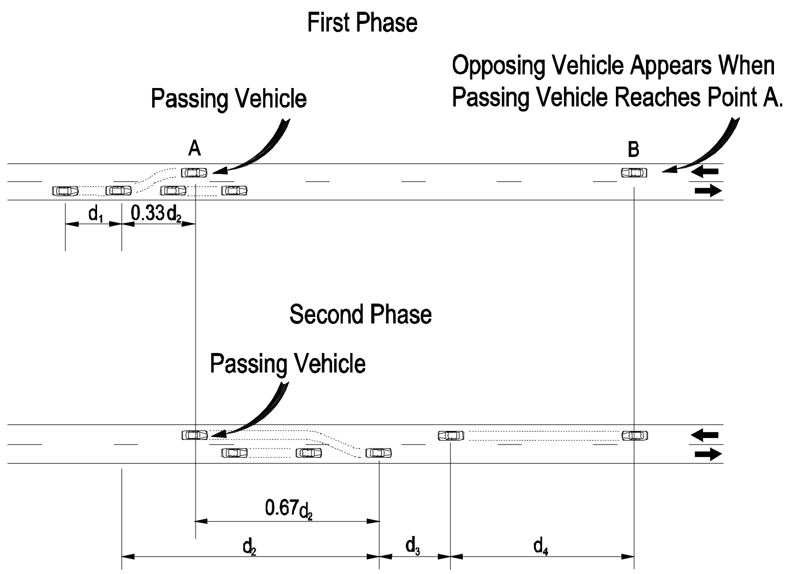
Appendix F provides additional design details and equations for intersection sight distance for each type of control, along with the summary tables and evaluation procedures.

2.8.3 Passing Sight Distance

Passing sight distance considerations are limited to two-lane, two-way highways. On these facilities, vehicles may overtake slower moving vehicles, and the passing maneuver must be accomplished on a lane used by opposing traffic.

The minimum passing sight distance for two-lane highways is determined from the sum of four distances as illustrated in Exhibit 2-10.

Exhibit 2-10
Elements of Passing Distance (Two-Lane Highways)



The following discussion provides the basic assumptions used to develop passing sight distance values for design:

Providing passing sight distance will make a crest curve flatter.

1. **Initial Maneuver Distance (d_1).** This is the distance traveled during the perception and reaction time and during the initial acceleration to the point of encroachment on the left lane. For the initial maneuver, the overtaken vehicle is assumed to be traveling at a uniform speed.
2. **Distance of Passing Vehicle in Left Lane (d_2).** This is the distance traveled by the passing vehicle while it occupies the left lane.
3. **Clearance Distance (d_3).** This is the distance between the passing vehicle at the end of its maneuver and the opposing vehicle.
4. **Opposing Vehicle Distance (d_4).** This is the distance traveled by an opposing vehicle during the time the passing vehicle occupies the left lane. The opposing vehicle appears after approximately one-third of the passing maneuver (d_2) has been accomplished. The opposing vehicle is assumed to be traveling at the same speed as the passing vehicle.

Exhibit 2-11 provides the minimum passing sight distance for design on two-lane, two-way highways.

**Exhibit 2-11
Minimum Passing
Sight Distance (Two-Lane Highways)**

Design Speed (mph)	Assumed Speeds		Minimum PSD for Design (ft)
	Passed Vehicle (mph)	Passing Vehicle (mph)	
20	8	20	400
25	13	25	450
30	18	30	500
35	23	35	550
40	28	40	600
45	33	45	700
50	38	50	800
55	43	55	900
60	48	60	1000
65	53	65	1100
70	58	70	1200
75	63	75	1300
80	68	80	1400

On rural reconstruction projects of two-lane highways, the design team should attempt to provide passing sight distance over as much of the highway length as practical. It will generally not be cost effective to make improvements to the horizontal and vertical alignment solely to increase the available passing sight distance. When determining the percent of passing sight distance, consider the following factors:

1. traffic volumes,
2. truck volumes, and
3. safety.

Passing sight distance is measured from a 3.5-foot height of eye to a 3.5 feet high object. The 3.5 feet height of object allows 0.8 feet of the top of a typical passenger car to be seen by the opposing driver.

2.8.3.1 Passing Lanes

The Traffic and Safety Bureau is responsible for conducting the study to justify the need for passing lanes.

Passing lanes are defined as added lanes provided in one or both directions of travel on a two-lane, two-way highway to improve passing opportunities. They may present a relatively low-cost improvement for traffic operations by breaking up traffic platoons and reducing delay on roadways with inadequate passing opportunities. Truck-climbing lanes are one type of passing lane used on steep grades to provide passenger cars with an opportunity to pass slow-moving trucks. The Traffic and Safety Bureau can provide additional information and criteria for the design of truck-climbing lanes.

Passing lanes other than truck-climbing lanes may be necessary on two-lane roadways where the desired level of service cannot be obtained. Passing lanes also may be determined to be necessary based on an engineering study that includes judgment, operational experience, and a capacity analysis. The use of a passing lane will be determined on a case-by-case basis. The Traffic and Safety Bureau is responsible for conducting the study to justify the need for passing lanes. For more information on passing lane guidance, see the FHWA publication *Low Cost Methods for Improving Traffic Operations on Two-Lane Roads*, Report No. FHWA-IP-87-2 *(11)*.

The FHWA publication also presents approximate adjustments which may be made to the highway capacity methodology in the *Highway Capacity Manual* to estimate the level-of-service benefits from adding passing lanes to two-way roadway facilities *(8, 11).*

As described in Section 2.8.1.4, scaling and recording sight distances on plans can also be beneficial for evaluating passing sight distances on two-lane highways. For two-lane highways, passing sight distance and stopping sight distance should be measured and recorded to allow for appropriate design decisions with the horizontal and vertical alignments. These records may be used to determine the markings of no-passing zones on two-lane highways, in accordance with criteria given in the *Manual on Uniform Traffic Control Devices (MUTCD) (12).* No-passing zones should be verified to fit field conditions.

2.8.4 Decision Sight Distance

While stopping sight distances are usually sufficient for typical drivers to navigate the roadway effectively, there are some situations when greater distances may be needed to allow drivers to make complex or sudden decisions. Decision sight distance may be considered in a location where the driver may be faced with multiple objects, pedestrians, design features, complex traffic control or complex surrounding land use, unique topographic conditions, and signage for multiple destinations. In these situations, drivers may need additional time and distance to react and make appropriate decisions.

Decision sight distance is the distance required for a driver to detect information that is difficult to perceive, to recognize the condition or its potential threat, to select an appropriate speed and path, and to initiate and complete complex maneuvers *(2)*. Decision sight distance provides drivers with additional length to maneuver their vehicles, compared to stopping sight distance. Exhibit 2-12 provides decision sight distances for each avoidance maneuver at various design speeds.

Exhibit 2-12
Decision Sight Distance

Design Speed (V) (mph)	Decision Sight Distances (ft) Avoidance Maneuver				
	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365
70	780	1410	1105	1275	1445
75	875	1545	1180	1365	1545
80	970	1685	1260	1455	1650

Avoidance Maneuver A: Stop on rural road (t = 3.0 s)
Avoidance Maneuver B: Stop on urban road (t = 9.1 s)
Avoidance Maneuver C: Speed/path/direction change on rural road (t varies between 10.2 and 11.2 s)
Avoidance Maneuver D: Speed/path/direction change on suburban road (t varies between 12.1 and 12.9 s)
Avoidance Maneuver E: Speed/path/direction change on urban road (t varies between 14.0 and 14.5 s)

Drivers performing evasive maneuvers may involve less risk and be preferable to stopping.

Drivers performing evasive maneuvers may involve less risk and be preferable to stopping. For the avoidance maneuvers shown in Exhibit 2-12, the pre-maneuver time (t) is greater than the braking reaction time for stopping sight distance to allow the driver additional time to detect and recognize the roadway or traffic situation, identify alternative maneuvers and initiate a response at critical locations on the roadway. The decision sight distance is dependent on the area type, such as rural or urban, and the type of maneuvers required to negotiate the given situation.

2.9 DESIGN EXCEPTIONS

The *RDM* presents numerous criteria on road design elements for application on individual road design projects. In general, the design team is responsible for making every reasonable effort to meet these criteria in the project design. However, this will not always be practical or appropriate. In addition, the performance-based design approach will guide the design team to take the project context and the intended project outcome into account when establishing the design controls and associated design criteria on a project-by-project basis. The design decisions can be documented through design exceptions. This section discusses MDT's procedures for identifying, justifying and processing exceptions to the geometric design criteria in the *RDM*.

Design exceptions are an effective way to document design decisions that occur throughout a project to meet desired outcomes and serve various users.

Design exception processes represent a means for the design team to implement design features that do not fall within the designated design criteria established by MDT. Historically, design exceptions yielded projects that took the form of Resurfacing, Restoration, and Rehabilitation (3R) projects, as states began to face the challenges of redesigning existing roadway facilities within an environment of increasing constraints. In essence, it is a form of documentation that shows the analysis and engineering judgment performed to design a roadway to fit the surrounding environment and local context.

As roadway networks become more built-out and the surrounding land uses make certain roadway improvements impractical, design exceptions will become increasingly embraced as a process with which to implement customized and flexible designs to better meet the needs of a constrained environment.

2.9.1 Design Elements

Information regarding the design elements can be found in the relevant chapters of the *RDM*, and the geometric design criteria for MDT design projects are summarized in the *MDT Geometric Design Standards (1)*.

The following describes the MDT standards for which design exceptions are required. The *Guidelines for Nomination of Pavement Projects (4)* provides additional information for design exceptions related to various types of projects.

Design exception requirements vary based on project work type; see the *Guidelines for Nomination of Pavement Projects (4).*

1. **Minimum design speed.** Design speed applies to all types of roadways in rural and urban areas.
2. **Minimum lane and shoulder widths**. This applies to variation in lane and/or shoulder widths for the following:
    a. Through travel lanes
    b. Auxiliary lanes
    c. Ramps
3. **Cross slopes on travel lanes**. This applies to travel lanes (through lanes, as well as auxiliary lanes) only, and does not apply to shoulders. The appropriate cross slope must be used, as defined by MDT criteria for the given surfacing type and whether the section is curbed or not.
4. **Side slopes**. This applies to all side slopes, including surfacing inslopes, as well as cut/fill slopes. If the proposed slope is steeper than the

Non-preferred ditch section includes narrowing, steepening, or creating a non-traversable ditch.

maximum specified by MDT criteria, a design exception is required. Additionally, MDT includes flat-bottom ditches in rural cut sections. While variations to the width and/or slope of this flat-bottom ditch do not specifically require a design exception, any modification that results in a non-preferred ditch section may require a design exception.

5. **Horizontal alignment elements**. This applies to the following elements of a horizontal alignment:
    a. Minimum radii. If the proposed curve radius is less than the minimum specified by MDT criteria, a design exception is required. This also applies to deflection angles without curves that exceed MDT criteria.
    b. Spiral curve selection. If a circular curve is proposed where a spiral curve is required per MDT criteria, a design exception is required.
    c. Minimum stopping sight distance. The sight line through the middle ordinate is typically the controlling criteria for sight distance at horizontal curves, particularly when the inside of the curve is in a cut section. If the stopping sight distance provided by the horizontal curve is less than the minimum specified by MDT criteria, a design exception is required.
6. **Superelevation rates.** Any variation from the appropriate superelevation rate for the proposed curve radius, as defined by MDT criteria, requires a design exception.
7. **Vertical alignment elements.** This applies to the following elements of a vertical alignment:
    a. Stopping sight distance. If the stopping sight distance provided by a crest or sag vertical curve is less than the minimum specified by MDT criteria, a design exception is required. Sight distance provided on sag vertical curves is based on headlight illumination in all cases, and based on line of sight when checking overhead sight obstructions.
    b. Grades. A design exception is required for grades that exceed MDT maximum grade criteria. If a proposed grade is flatter than the minimum specified by MDT criteria, a design exception is not needed, though drainage should be a major design consideration in this case.
8. **Vertical clearances**. Any proposed vertical clearance that does not meet minimum MDT criteria requires a design exception.
9. **Roadside clear zones.** This applies to obstructions that lie within the clear zone. An obstruction is anything harmful to an errant vehicle, such as, but not limited to, bridge piers, critical side slopes, non-preferred ditch sections, non-traversable culvert ends, sign bridges, or any body of water of sufficient depth. If the proposed roadway clear zone does not meet the width specified by MDT criteria, a design exception is required.
10. **Intersection sight distance.** All intersections, including private, public, and farm field approaches that do not meet the necessary intersection sight distance, as identified in Section 2.8.2, require a design exception.

11. **Structural capacity.** Any structures that do not meet minimum structural capacity, as identified in the *MDT Bridge Manual*, require a design exception.

2.9.2 Considerations

Design exceptions should be developed by considering geometric design, operations, and safety for the project segment, consistent with the corridor goals. Mitigating features and countermeasures should be considered in the analysis. The objective is to produce a design that is geometrically feasible, operates effectively, and provides a safe environment for various modes of travel.

2.9.2.1 Design

The geometric design of a roadway is limited by environmental constraints, including natural terrain and availability of right-of-way. A design exception may be submitted with the objective of preventing unnecessary changes to the local environment or to accommodate inflexible geographic constraints.

2.9.2.2 Operations

Roadways should be designed to accommodate existing and future demands of various modes of travel, including motor vehicles, pedestrians, bicyclists, and heavy vehicles. An operational analysis should show that the design exception will accommodate various users and enable the roadway to operate effectively. The *Highway Capacity Manual (HCM)* provides methodologies to analyze the operational needs for various users *(8)*.

2.9.2.3 Safety

The design exception should maintain or improve the safety conditions for various roadway users. In addition to the standard safety analyses using historical crash data, the *Highway Safety Manual (HSM)* can offer additional insights to improve roadway safety *(13)*.

The *HSM* provides science-based guidance for conducting roadway safety analysis. This includes conducting roadway network screening using the performance measures contained in Part B of *HSM* as well as evaluating countermeasures and potential safety effects of roadway geometry using the information in Parts C and D of the *HSM*. The information in Parts C and D are particularly useful for evaluating the potential safety performance (e.g., number and severity of crashes) for alternative roadway cross sections and alignments. In contexts where the *HSM* is applicable, the *HSM* provides a means to quantitatively evaluate safety and compare the potential tradeoffs of different design decisions *(13)*. In addition, FHWA maintains a Crash Modification Factors (CMF) Clearinghouse that provides an online, searchable database with the findings regarding the safety effects of specific design features and treatments *(14)*.

The *HSM* is not applicable to every context, and therefore the design team needs to pay close attention to when the methodologies do and do not apply. The *HSM* contains specific guidance regarding the different roadway contexts to which the information is applicable. Similarly, the information in the CMF

Clearinghouse is not universally applicable to every context and some of the information in the database should be considered preliminary results that are not suitable for application in-practice, but instead considered as an area of needed research. The CMF Clearinghouse provides a star rating for each CMF to help the design team differentiate between the CMFs sufficiently reliable to be used in practice versus those that require additional research *(14)*.

MDT's *Safety Information Management System (SIMS)* is a database and analysis system that allows users to screen the roadway network and complete reviews of specific locations using HSM tools and methodologies. In addition, MDT uses Safety Performance Functions (SPF), which reflects the relationship between traffic exposure measured in Annual Average Daily Traffic (AADT), and crash count for a unit of road section measured in crashes per mile per year. The SPF models provide an estimate of the normal or expected crash frequency and severity for a range of AADT among similar roadway facilities.

Development of the SPF lends itself well to the conceptual formulation of the Level of Service of Safety (LOSS). The concept of level of service uses quantitative measures and qualitative descriptions that characterize safety of a roadway segment in reference to its expected frequency and severity. If the level of safety predicted by the SPF will represent a normal or expected number of crashes at a specific level of AADT, then the degree of deviation from the norm can be stratified to represent specific levels of safety.

LOSS reflects how the roadway segment is performing in regard to its expected crash frequency and severity at a specific level of ADT. If a safety problem is present, LOSS will only describe its magnitude from a frequency and severity standpoint. The nature of the problem is determined through diagnostic analysis using direct diagnostics and pattern recognition techniques.

2.9.3 Process/Application

A design exception submitted to MDT will be reviewed by MDT and may also be reviewed by the Federal Highway Administration (FHWA). The submittal documentation will not differ based on the reviewing agency.

The MDT design exception process applies to all capital improvement projects under the jurisdiction of MDT, as well as improvements along MDT roadway facilities by private developers. The projects with design elements that do not comply with the MDT design standards will require a design exception submittal.

Design exceptions will be submitted to FHWA for all Projects of Division Interest (PoDI). PoDI are those projects that have an elevated risk, contain elements of higher risk, or present a meaningful opportunity for FHWA involvement to enhance the meeting of program or project objectives. Design exceptions for PoDI require FHWA approval. Design exceptions will be submitted internally to MDT for all other projects.

2.9.4 Documentation Format

The type and detail of the documentation needed to justify a design exception will be determined on a case-by-case basis depending on the type of project and type of design exception being requested. The template for documenting a design exception is available on the MDT Website at the following link:

MDT Design Exception Template

Comprehensive documentation, including design, mitigation measures, operations and safety considerations, allows the design exception reviewers to have a clear understanding of the project context and justification for the exception to the design criteria. FHWA memorandum, *Revisions to Controlling Criteria for Design and Documentation for Design Exceptions* and FHWA document, *Mitigation Strategies for Design Exceptions* provide additional information *(15, 16)*.

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MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 3

Horizontal Alignment

September 2016

Contents

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Chapter 3

Horizontal Alignment

The horizontal alignment of a roadway, as well as the vertical alignment and cross section, has an impact on the safety and operational performance for all road users, as well as construction and maintenance costs. This chapter presents the basic design principles and approach for designing horizontal alignment elements, including a discussion of the different types of horizontal curves and methods of achieving superelevation. The *Montana Department of Transportation (MDT) Geometric Design Standards* provides specific horizontal alignment standards relative to a roadway's functional classification *(1)*. Example calculations and detailed definitions associated with this chapter can be found in Appendix K.

3.1 DESIGN PRINCIPLES AND APPROACH

The use of horizontal curves in roadway design should contribute to the overall safety of the roadway and enhance the aesthetic appearance of the roadway for road users. The design team should adhere to general design principles and limiting criteria discussed in the context of the five types of horizontal curves in the following sections.

3.1.1 Coordination with Other Design Elements

The horizontal alignment chosen should reflect design consistency, encourage appropriate driver behavior, and consider trade-offs relative to other engineering design parameters.

The horizontal alignment works in conjunction with other design elements, such as the vertical alignment and cross section elements, to achieve the best possible design for the roadway. The horizontal alignment should provide a design consistent with driver expectation, avoiding abrupt, unexpected changes or sharp curves following long tangents. The alignment should be as directional as practical, using the smallest practical deflection (Δ) angles and longest practical curve lengths, while still generally conforming to the natural topography and remaining consistent with other existing physical and economic constraints. Where possible, it is best to avoid abrupt alignment reversals or "S" curves by providing a sufficient length of tangent roadway between reversing curves. The horizontal alignment should also be consistent with roadway conditions beyond the project extents to meet driver expectation.

***NCHRP Report 785* provides additional details on the relationship between various design elements and performance measures *(2)*.**

Consideration of the above principles should also be consistent with vertical design elements. Best practice is to avoid a horizontal alignment which constrains the vertical design or creates areas of excess cut and/or fill. The vertical and horizontal design should be harmonious rather than allowing one to directly dictate the other. Vertical alignment and coordination between vertical and horizontal design is discussed in Chapter 4, Section 4.1.3.

The design of the horizontal alignment should be coordinated with features outside of the roadway itself. These may include environmentally sensitive or culturally significant areas adjacent to the project, existing infrastructure, and intersections. Coordination with these elements should consider all of the above mentioned items related to consistency and vertical design. Additional guidance on basic horizontal design controls and coordination with other design elements can be found in Chapter 2, Section 2.9.1.

Chapter 1, Section 1.2 provides additional information on applying a performance-based design approach.

The *MDT Geometric Design Standards* provide the design team with design criteria for the horizontal design elements *(1)*. The criteria provide a starting point for the design team to make a thoughtful evaluation of the project needs in consideration of the specific context. Design decisions may result in reasonable exceptions to the design criteria in order to meet the overall project purpose. A performance-based design framework can provide tools for making these decisions and design exceptions can help document these design choices.

3.1.2 Horizontal Alignment Considerations

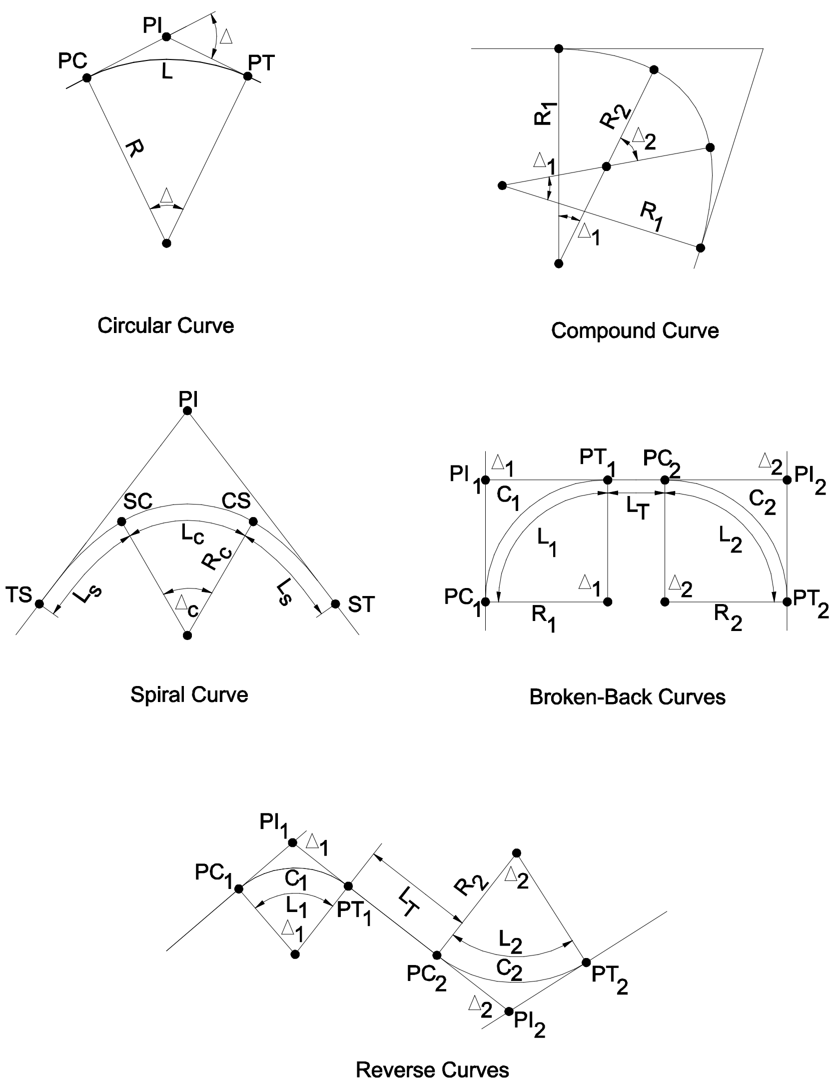
There are five types of horizontal curves that can be used to satisfy the horizontal constraints and considerations discussed above. The five types of horizontal curves are described below and illustrated in Exhibit 3-1.

1. **Circular curves** are continuous arcs of constant radii that achieve the necessary roadway deflection without an entering or exiting transition. Circular curves are also referred to as simple curves.
2. **Compound curves** are a series of two or more adjacent horizontal curves with deflections in the same direction and different radii.
3. **Spiral curves** are curvature arrangements that gradually increase from the tangent section (radius of infinity) to the radius of the circular curve or vice versa. These types of curves are more consistent with the transitional characteristics of vehicular turning paths used to transition between a tangent section and a circular curve.
4. **Broken-back curves** are two closely-spaced horizontal curves, of the same or different radii, with deflections in the same direction and a short tangent between the curves.
5. **Reverse curves** are two circular curves with deflections in opposite directions joined at a common point or by a relatively short tangent.

Within the five types of horizontal curves, the following reference points are used:

- Point of Curvature (PC)
- Point of Intersection (PI)
- Point of Tangency (PT)
- Length of Curve (L)
- Spiral to Curve (SC)
- Curve to Spiral (CS)
- Tangent to Spiral (TS)
- Spiral to Tangent (ST)
- Radius of Curve (R)

Exhibit 3-1
Schematic of Horizontal Alignment Curves



An important consideration in horizontal alignment design is its effect on the cross section. In particular, the use of normal crown sections on tangents and superelevation on horizontal curves requires considering the axis of rotation for transitioning to and from the superelevated sections. Axis of rotation about the centerline profile is the preferred rotation method for all rural or urban roadways without a median. Axis of rotation methods, and design considerations for each, are discussed in Section 3.3.5.

If the project extents include a bridge section, it is important to consider the bridge approach and structure as a unique part of the horizontal alignment. In general, it is undesirable to locate a bridge and its approach slabs on a horizontal curve of any type. Additional guidance and considerations for horizontal curves near bridges is provided in Section 3.3.10.

Sight obstructions on the inside of a horizontal curve are defined as obstacles which interfere with the line of sight on a continuous basis. These may include walls, cut slopes, wooded areas, buildings, and high farm crops. In general, point obstacles such as traffic signs and utility poles are not considered sight obstructions on the inside of horizontal curves. The design team should examine each curve individually to determine whether it is necessary to remove an obstruction or to adjust the horizontal alignment to obtain the required sight distance. Chapter 2, Section 2.8.1.1 provides additional information for determining horizontal sight distance requirements.

Refer to Chapter 2, Section 2.2.1 for detailed functional classification descriptions of rural and urban roadways.

Throughout this chapter, the following general categories are used to describe standards and parameters for horizontal curves and superelevation for different types of roadways:

1. **Rural Conditions.** All rural (outside the boundaries of urban areas) roadways and urban roadways where the design speed (V) > 45mph.
2. **Urban Conditions.** All roadways within the boundaries of an urban area where the design speed (V) ≤ 45mph.

3.2 HORIZONTAL CURVES

Once the constraints and parameters of the horizontal alignment have been established, the design team can begin the process of selecting the appropriate curve type and radius as discussed below. This section also discusses the use of minimum radii, maximum deflection without curve, and minimum length of curve for use in unique design situations. Basic equations for designing horizontal curves are provided in this chapter. Detailed calculation examples are provided in Appendix K.

It may not be feasible to meet some criteria for rural roadways in mountainous terrain. For these situations, the use of reverse curves, compound curves, and/or circular curves with 7-percent or greater superelevation may help the design team match the existing terrain.

3.2.1 Selection of Curve Type

The following presents MDT practice for the selection of the type of horizontal curve based on the type of roadway:

1. **Rural Conditions**. Based on the superelevation rate (*e*) criteria for the horizontal curve (Section 3.3.2), the following will apply:
   a. Superelevation < 7%: Use a circular curve.
   b. Superelevation ≥ 7%: Use a spiral curve.

Compound curves are typically not allowed on these roadways, except in transitional areas. For example, a larger radius circular curve approaching a smaller radius circular curve and then leaving the smaller radius circular curve with a larger radius circular curve may be appropriate to match existing topography.

2. **Urban Conditions.** Typically, circular curves will be used on roadways in urban conditions. In urban areas, if necessary, it is acceptable to use compound curves on the mainline to:
    a. Avoid obstructions,
    b. Avoid right-of-way problems, and/or
    c. Fit the existing topography.

Where used, compound curves on the mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve ($R_1 \leq 1.5R_2$, where R_1 is the flatter curve).

3.2.2 Calculation of Curve Radii

The point-mass formula is used to define vehicular operation around a curve. Where the curve is expressed using its radius, the basic equation for a circular curve is:

$$R = \frac{V^2}{15(e+f)}$$

Equation 3.2-1

Where:

R = radius of curve, feet (ft)

e = superelevation rate, decimal

f = side-friction factor, decimal (from Exhibit 3-2)

V = design speed, miles per hour (mph)

Establishing horizontal curvature criteria requires a selection of various factors in the basic curve equation (Equation 3.2-1). These include the selection of maximum side-friction factors (*f*) and the distribution method between side friction and superelevation. For roadway mainlines, the theoretical basis will be one of the following:

1. **Rural Conditions.** The theoretical basis for horizontal curvature assuming rural conditions includes:
    a. Relatively low maximum side-friction factors (that is, a relatively small level of driver discomfort); and
    b. Use of American Association of State Highway and Transportation Officials (AASHTO) Method 5 to distribute side friction and superelevation *(3)*.

    AASHTO Method 5 distributes side friction and superelevation such that each element is used simultaneously to offset the outward pull of the vehicle traveling around the curve.

2. **Urban Conditions.** The theoretical basis for horizontal curvature assuming urban conditions includes:
    a. Relatively high maximum side-friction factors to reflect a higher level of driver acceptance of discomfort; and

b. Use of AASHTO Method 2 to distribute side friction and superelevation.

Check local design criteria for off-system roadways.

AASHTO Method 2 distributes side friction and superelevation such that side friction alone is used, up to the maximum side friction factor (f_{max}), to offset the outward pull of the vehicle traveling around the curve. Only then is superelevation introduced.

3.2.3 Minimum Radii

The minimum radius of curvature is determined assuming the maximum rate of superelevation (e_{max}) and the maximum side friction factor (f_{max}), while still maintaining a level of driver comfort and a margin of safety against skidding or vehicle rollover. Once the minimum radius is determined for a given design speed, the ranges of appropriate radii for curves with less than the maximum superelevation rate can be determined for the given design speed.

Exhibits 3-2 and 3-3 present the minimum radii (R_{min}) for rural and urban roadways. To define R_{min}, a maximum superelevation rate must be selected. See Section 3.3.1 for MDT criteria for e_{max}.

Exhibit 3-2
Minimum Radii for Rural Conditions

Design Speed, V (mph)	e_{max} (percent)	f_{max}	Minimum Radii, R_{min} (ft)
20	8.0%	0.27	80
25	8.0%	0.23	140
30	8.0%	0.20	220
35	8.0%	0.18	320
40	8.0%	0.16	450
45	8.0%	0.15	590
50	8.0%	0.14	760
55	8.0%	0.13	960
60	8.0%	0.12	1200
65	8.0%	0.11	1480
70	8.0%	0.10	1810
75	8.0%	0.09	2210
80	8.0%	0.08	2670

Note: R_{min} is based on Equation 3.2-1 rounded up to the nearest 10-foot increment. R_{min} is typically measured at the center of gravity of vehicles in the inside most lane.

Exhibit 3-3
Minimum Radii for Urban Conditions

Design Speed, V (mph)	e_{max}	f_{max}	Minimum Radii, R_{min} (ft)
20	4.0%	0.27	86
25	4.0%	0.23	154
30	4.0%	0.20	250
35	4.0%	0.18	371
40	4.0%	0.16	533
45	4.0%	0.15	711

Note: R_{min} is based on Equation 3.2-1 rounded to the nearest 1-foot increment. R_{min} is typically measured at the center of gravity of vehicles in the inside most lane.

Horizontal curve radii larger than design minimums should be used where feasible.

When selecting a curve radius, the design team should again consider the desired performance of the roadway and the existing and future constraints. The values provided in Exhibits 3-2 and 3-3 are design minimums, but a larger radius should be selected if it better fits the topography and constraints of an area. If a smaller radius, and therefore a lower design speed, is appropriate to fit the topography and constraints of the area, the design team shall obtain a design exception. See Chapter 2, Section 2.9 for MDT procedures on design exceptions. Also, if the design speed for the horizontal curve is lower than the posted speed, the design team should coordinate with the Traffic and Safety Bureau. Appropriate warning signage for the curve may be required according to the latest *MUTCD* guidance (*4*).

3.2.4 Maximum Deflection without a Curve

It may be appropriate to design a roadway without a horizontal curve where small deflection angles (Δ) are present. As a guide, the design team may retain deflection angles of about 1 degree or less in urban areas and 0.5 degrees or less in rural areas. In these cases, the absence of a horizontal curve will not likely affect driver response or aesthetics.

For urban intersections, deflection angles greater than 1 degree without a horizontal curve may be acceptable based on an evaluation of the design speed, traffic volumes, functional class, and existing/future signalization. A design exception for the minimum radius criterion may be necessary for use of a deflection angle. See Chapter 2, Section 2.9 for MDT procedures on design exceptions.

3.2.5 Minimum Length of Curve

If none of these criteria can be met, the design team should document this in the Alignment and Grade Review Report.

Short horizontal curves may provide the driver with the appearance of a kink in the alignment. To improve the aesthetics of the roadway, the design team should use longer curves, if practical, even if not necessary for engineering reasons. The following guidance should be used to establish minimum curve lengths for deflection angles (Δ) of 5 degrees or less:

1. **Rural Conditions.** Use the following criteria to achieve the minimum curve length:
   a. The minimum radius that results in a normal crown cross slope.
   b. The length of curve in feet = 15*V*, where *V* is the design speed in mph.
   c. A 500-foot length of curve for a 5-degree deflection, add 100 feet for each 1-degree decrease in the central angle.
2. **Urban Conditions.** The minimum length of curves in urban conditions will be determined on a case-by-case basis.

3.3 SUPERELEVATION

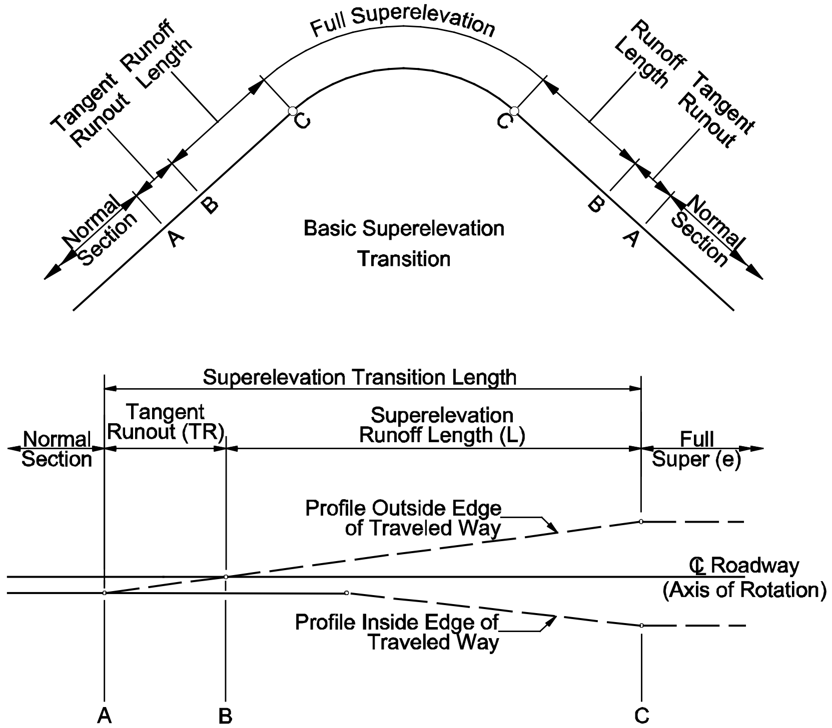
It may not always be practical or desirable to provide superelevation, particularly on low-speed urban roadways.

Another element of horizontal design is the cross slope of the roadway and how it influences the horizontal curve design. As used in this section, the terms below are defined as follows:

1. **Superelevation**. The amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.
2. **Transition Length**. The superelevation transition length is the distance required to transition the roadway from a normal crown (*NC*) section to a full superelevation. Superelevation transition length is the sum of the tangent runout (*TR*) and superelevation runoff (*L*) distances:
   a. **Tangent Runout (*TR*)**. Tangent runout is the distance needed to transition the roadway from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., where the outside lane(s) is level).
   b. **Superelevation Runoff (*L*)**. Superelevation runoff is the distance needed to transition the cross slope from the end of the tangent runout to a section that is sloped at the design superelevation rate.
3. **Axis of Rotation**. The superelevation axis of rotation is the line about which the pavement is rotated to superelevate the roadway. This line will maintain the normal roadway profile through the curve.

Exhibit 3-4 provides an illustration of these terms in both plan and profile views.

Exhibit 3-4
Superelevation Terms



The following discusses MDT practice for the application of superelevation to each curve type on both rural and urban roadways.

3.3.1 Maximum Superelevation Rate

The selection of a maximum rate of superelevation (e_{max}) depends upon several factors; these include urban/rural location, type of roadway, and prevalent climatic conditions. MDT has adopted the following criteria for the selection of e_{max}:

1. **Rural Conditions.** An e_{max} = 8% is used for rural conditions.
2. **Urban Conditions.** When used, an e_{max} = 4% is appropriate for urban conditions.

3.3.2 Superelevation Rates

Based on the selection of e_{max} and the roadway type (rural or urban), the following criteria will be used to determine the superelevation rate for combinations of curve radii (*R*) and design speed (*V*) and to select the minimum length of transition.

Exhibits 3-5 and 3-6 apply to two-lane, two-way roadways and multilane roadways, respectively, in rural conditions where e_{max} = 8%. Under rural conditions distribution of *e* and *f* over a range of curves is based on AASHTO Method 5 *(3)*. Exhibit 3-7 applies to roadways in urban conditions, where e_{max} = 4%. Under urban conditions, distribution of *e* and *f* over a range of curves is based on AASHTO Method 2 *(3)*. See Chapter 2, Section 2.9 for MDT procedures on design exceptions.

Exhibit 3-5 Rate of Superelevation and Minimum Length of Transition (Two-Lane, Two-Way Roadways in Rural Conditions)

e	V = 30 mph			V = 35 mph			V = 40 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 3240	0	0	R ≥ 4260	0	0	R ≥ 5410	0	0
2.0%	3240 > R ≥ 2370	36	36	4260 > R ≥ 3120	40	40	5410 > R ≥ 3970	42	42
3.0%	2370 > R ≥ 1480	54	36	3120 > R ≥ 1960	60	40	3970 > R ≥ 2510	63	42
4.0%	1480 > R ≥ 1030	72	36	1960 > R ≥ 1370	80	40	2510 > R ≥ 1770	84	42
5.0%	1030 > R ≥ 730	90	36	1370 > R ≥ 1000	100	40	1770 > R ≥ 1310	105	42
6.0%	730 > R ≥ 510	108	36	1000 > R ≥ 720	120	40	1310 > R ≥ 970	126	42
7.0%	510 > R ≥ 360	126	36	720 > R ≥ 520	140	40	970 > R ≥ 720	147	42
8.0%	360 > R ≥ 220	144	36	520 > R ≥ 320	160	40	720 > R ≥ 450	168	42
	R_{min} = 220 ft			R_{min} = 320 ft			R_{min} = 450 ft		

e	V = 45 mph			V = 50 mph			V = 55 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 6710	0	0	R ≥ 8150	0	0	R ≥ 9720	0	0
2.0%	6710 > R ≥ 4930	44	44	8150 > R ≥ 5990	48	48	9720 > R ≥ 7150	52	52
3.0%	4930 > R ≥ 3130	66	44	5990 > R ≥ 3820	72	48	7150 > R ≥ 4580	78	52
4.0%	3130 > R ≥ 2220	88	44	3820 > R ≥ 2720	96	48	4580 > R ≥ 3270	104	52
5.0%	2220 > R ≥ 1650	110	44	2720 > R ≥ 2040	120	48	3270 > R ≥ 2470	130	52
6.0%	1650 > R ≥ 1250	132	44	2040 > R ≥ 1560	144	48	2470 > R ≥ 1920	156	52
7.0%	1250 > R ≥ 940	154	44	1560 > R ≥ 1190	168	48	1920 > R ≥ 1480	182	52
8.0%	940 > R ≥ 590	176	44	1190 > R ≥ 760	192	48	1480 > R ≥ 960	208	52
	R_{min} = 590 ft			R_{min} = 760 ft			R_{min} = 960 ft		

e	V = 60 mph			V = 70 mph			V = 80 mph		
	R(ft)	Trans. Length		R(ft)	Trans. Length		R(ft)	Trans. Length	
		L(ft)	TR(ft)		L(ft)	TR(ft)		L(ft)	TR(ft)
NC	R ≥ 11,500	0	0	R ≥ 14,500	0	0	R ≥ 17,800	0	0
2.0%	11,500 > R ≥ 8440	54	54	14,500 > R ≥ 10,700	60	60	17,800 > R ≥ 13,300	70	70
3.0%	8440 > R ≥ 5420	81	54	10,700 > R ≥ 6930	90	60	13,300 > R ≥ 8700	105	70
4.0%	5420 > R ≥ 3890	108	54	6930 > R ≥ 5050	120	60	8700 > R ≥ 6420	140	70
5.0%	3890 > R ≥ 2960	135	54	5050 > R ≥ 3910	150	60	6420 > R ≥ 5050	175	70
6.0%	2960 > R ≥ 2320	162	54	3910 > R ≥ 3150	180	60	5050 > R ≥ 4140	210	70
7.0%	2320 > R ≥ 1820	189	54	3150 > R ≥ 2580	210	60	4140 > R ≥ 3480	245	70
8.0%	1820 > R ≥ 1200	216	54	2580 > R ≥ 1810	240	60	3480 > R ≥ 2670	280	70
	R_{min} = 1200 ft			R_{min} = 1810 ft			R_{min} = 2670 ft		

Key:

e_{max} = 8.0%
Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

Exhibit 3-6 Rate of Superelevation and Minimum Length of Transition (Multilane Roadways in Rural Conditions)

e	V = 30 mph R(ft)	V = 30 mph L(ft)	V = 30 mph TR(ft)	V = 35 mph R(ft)	V = 35 mph L(ft)	V = 35 mph TR(ft)	V = 40 mph R(ft)	V = 40 mph L(ft)	V = 40 mph TR(ft)
NC	R ≥ 3240	0	0	R ≥ 4260	0	0	R ≥ 5410	0	0
2.0%	3240 > R ≥ 2370	56	56	4260 > R ≥ 3120	58	58	5410 > R ≥ 3970	62	62
3.0%	2370 > R ≥ 1480	84	56	3120 > R ≥ 1960	87	58	3970 > R ≥ 2510	93	62
4.0%	1480 > R ≥ 1030	112	56	1960 > R ≥ 1370	116	58	2510 > R ≥ 1770	124	62
5.0%	1030 > R ≥ 730	140	56	1370 > R ≥ 1000	145	58	1770 > R ≥ 1310	155	62
6.0%	730 > R ≥ 510	168	56	1000 > R ≥ 720	174	58	1310 > R ≥ 970	186	62
7.0%	510 > R ≥ 360	196	56	720 > R ≥ 520	203	58	970 > R ≥ 720	217	62
8.0%	360 > R ≥ 220	224	56	520 > R ≥ 320	232	58	720 > R ≥ 450	248	62
	R_{min} = 220 ft			R_{min} = 320 ft			R_{min} = 450 ft		

e	V = 45 mph R(ft)	V = 45 mph L(ft)	V = 45 mph TR(ft)	V = 50 mph R(ft)	V = 50 mph L(ft)	V = 50 mph TR(ft)	V = 55 mph R(ft)	V = 55 mph L(ft)	V = 55 mph TR(ft)
NC	R ≥ 6710	0	0	R ≥ 8150	0	0	R ≥ 9720	0	0
2.0%	6710 > R ≥ 4930	68	68	8150 > R ≥ 5990	72	72	9720 > R ≥ 7150	78	78
3.0%	4930 > R ≥ 3130	102	68	5990 > R ≥ 3820	108	72	7150 > R ≥ 4580	117	78
4.0%	3130 > R ≥ 2220	136	68	3820 > R ≥ 2720	144	72	4580 > R ≥ 3270	156	78
5.0%	2220 > R ≥ 1650	170	68	2720 > R ≥ 2040	180	72	3270 > R ≥ 2470	195	78
6.0%	1650 > R ≥ 1250	204	68	2040 > R ≥ 1560	216	72	2470 > R ≥ 1920	234	78
7.0%	1250 > R ≥ 940	238	68	1560 > R ≥ 1190	252	72	1920 > R ≥ 1480	273	78
8.0%	940 > R ≥ 590	272	68	1190 > R ≥ 760	288	72	1480 > R ≥ 960	312	78
	R_{min} = 590 ft			R_{min} = 760 ft			R_{min} = 960 ft		

e	V = 60 mph R(ft)	V = 60 mph L(ft)	V = 60 mph TR(ft)	V = 70 mph R(ft)	V = 70 mph L(ft)	V = 70 mph TR(ft)	V = 80 mph R(ft)	V = 80 mph L(ft)	V = 80 mph TR(ft)
NC	R ≥ 11,500	0	0	R ≥ 14,500	0	0	R ≥ 17,800	0	0
2.0%	11,500 > R ≥ 8440	80	80	14,500 > R ≥ 10,700	90	90	17,800 > R ≥ 13,300	104	104
3.0%	8440 > R ≥ 5420	120	80	10,700 > R ≥ 6930	135	90	13,300 > R ≥ 8700	156	104
4.0%	5420 > R ≥ 3890	160	80	6930 > R ≥ 5050	180	90	8700 > R ≥ 6420	208	104
5.0%	3890 > R ≥ 2960	200	80	5050 > R ≥ 3910	225	90	6420 > R ≥ 5050	260	104
6.0%	2960 > R ≥ 2320	240	80	3910 > R ≥ 3150	270	90	5050 > R ≥ 4140	312	104
7.0%	2320 > R ≥ 1820	280	80	3150 > R ≥ 2580	315	90	4140 > R ≥ 3480	364	104
8.0%	1820 > R ≥ 1200	320	80	2580 > R ≥ 1810	360	90	3480 > R ≥ 2670	416	104
	R_{min} = 1200 ft			R_{min} = 1810 ft			R_{min} = 2670 ft		

Key:

e_{max} = 8.0%
Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

Exhibit 3-7 Rate of Superelevation and Minimum Length of Transition (Urban Conditions)

e	V = 20 mph					V = 25 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 107	0	0	0	0	R ≥ 198	0	0	0	0
2.0%	107 > R ≥ 92	32	32	50	50	198 > R ≥ 167	34	34	52	52
3.0%	92 > R ≥ 89	48	32	75	50	167 > R ≥ 160	51	34	78	52
4.0%	89 > R ≥ 86	64	32	100	50	160 > R ≥ 154	68	34	104	52
	Rmin = 86 ft					R_{min} = 154 ft				

e	V = 30 mph					V = 35 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 333	0	0	0	0	R ≥ 510	0	0	0	0
2.0%	333 > R ≥ 273	36	36	56	56	510 > R ≥ 408	40	40	58	58
3.0%	273 > R ≥ 261	54	36	84	56	408 > R ≥ 389	60	40	87	58
4.0%	261 > R ≥ 250	72	36	112	56	389 > R ≥ 371	80	40	116	58
	R_{min} = 250 ft					R_{min} = 371 ft				

e	V = 40 mph					V = 45 mph				
	R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)		R(ft)	Trans. Length (Two-Lane)		Trans. Length (Multilane)	
		L(ft)	TR(ft)	L(ft)	TR(ft)		L(ft)	TR(ft)	L(ft)	TR(ft)
NC	R ≥ 762	0	0	0	0	R ≥ 1039	0	0	0	0
2.0%	762 > R ≥ 593	42	42	62	62	1039 > R ≥ 794	44	44	68	68
3.0%	593 > R ≥ 561	63	42	93	62	794 > R ≥ 750	66	44	102	68
4.0%	561 > R ≥ 533	84	42	124	62	750 > R ≥ 711	88	44	136	68
	R_{min} = 533 ft					R_{min} = 711 ft				

Key:

e_{max} = 4.0%
Lane width = 12 ft (L & TR values for other lane widths can be determined using Equations 3.3-1 & 3.3-2, respectively)
R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 2.0%

3.3.3 Minimum Radii without Superelevation

A horizontal curve with a sufficiently large radius does not require superelevation, and the normal crown (*NC*) used on tangent sections can be maintained throughout the curve for both rural and urban roadways. Exhibits 3-5 and 3-6 indicate the threshold (or minimum) radius for a normal crown section at various design speeds for rural conditions. Exhibit 3-7 indicates the threshold (or minimum) radius for a normal crown section at various design speeds for urban conditions. The transition length values shown in Exhibits 3-5 through 3-7 are calculated based on Equations 3.3-1 through 3.3-3 and rounded for design. Equations 3.3-1 through 3.3-3 can be used to calculate values for conditions other than those presented in Exhibits 3-5 through 3-7.

3.3.4 Transition Length

The following outlines MDT procedure for determining the superelevation transition length for different types of roadways under both rural and urban conditions.

Two-Lane, Two-Way Roadways in Rural Conditions. To calculate the superelevation transition length, the superelevation runoff (*L*) and tangent runout (*TR*) must first be calculated. Exhibit 3-5 presents the superelevation runoff lengths for two-lane, two-way roadways in rural conditions for various combinations of curve radii, design speed, and superelevation rate. The superelevation runoff can be calculated from Equation 3.3-1 for a two-lane roadway.

$$L = e \times W \times RS$$

Equation 3.3-1

where:

L = Superelevation runoff length for a two-lane roadway, feet

W = Width of travel lane, feet

RS = Reciprocal of relative longitudinal slope between the roadway centerline and outside edge of traveled way (see Exhibit 3-8)

e = Superelevation rate, decimal

Exhibit 3-5 presents the tangent runout distances based on a 2-percent normal crown for two-lane, two-way roadways in rural conditions. For roadways having a normal crown other than 2-percent, use Equation 3.3-2 to compute the tangent runout distance:

$$TR = \frac{S_{NORMAL}}{e/L} = \frac{(S_{NORMAL})(L)}{e}$$

Equation 3.3-2

where:

TR = Tangent runout distance for a two-lane roadway, feet

S_{NORMAL} = Travel lane cross slope on tangent (typically 0.02), decimal

e = Design superelevation rate (that is, full superelevation for horizontal curve), decimal

L = Superelevation runoff length for a two-lane roadway, feet

Exhibit 3-8
Maximum Relative Longitudinal Slopes for Two-Lane Roadways

Design Speed (mph)	RS	Maximum Relative Longitudinal Slope, G(%)*
30	152	0.66
35	161	0.62
40	172	0.58
45	185	0.54
50	200	0.50
55	213	0.47
60	222	0.45
70	250	0.40
80	286	0.35

*G(%) = 1/RS x 100

Multilane Roadways in Rural Conditions. For multilane roadways in rural conditions, the superelevation runoff will be calculated from Equation 3.3-3. For rotation of three- to four-lane roadways, the superelevation runoff length will be 1.5 times that for two-lane roadways. For rotation of roadways with more than four lanes, the superelevation runoff length will be 2.0 times that for two-lane roadways.

Equation 3.3-3

$$L = C \times L_{Two\text{-}lane\ roadways}$$

C = 1.5, for three- to four-lane roadways
C = 2.0, for roadways with more than four lanes

The tangent runout for multilane roadways in rural conditions is calculated from Equation 3.3-2. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff. Exhibit 3-6 summarizes the superelevation runoff and tangent runout distances for multilane roadways in rural conditions for various combinations of curve radii, design speed, and superelevation rate.

Urban Conditions. For two-lane roadways in urban conditions, the superelevation runoff and tangent runout can be calculated from the equations used for two-lane roadways under rural conditions. For multilane roadways in urban conditions the superelevation runoff and tangent runout can be calculated from the equations used for multilane roadways under rural conditions. Exhibit 3-7 summarizes the superelevation runoff and tangent runout for various combinations of superelevation rates and design speed.

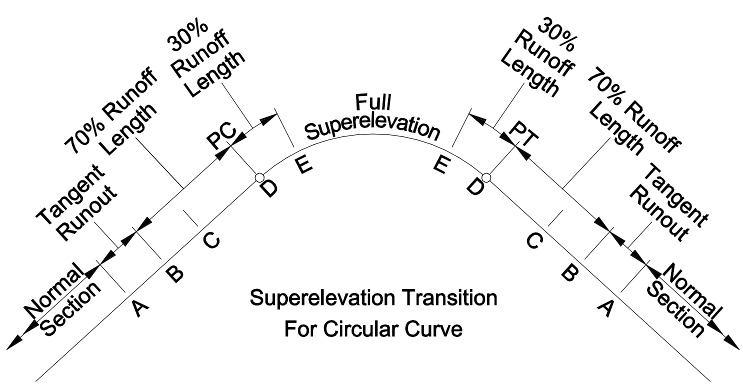
3.3.4.1 Application of Transition Length

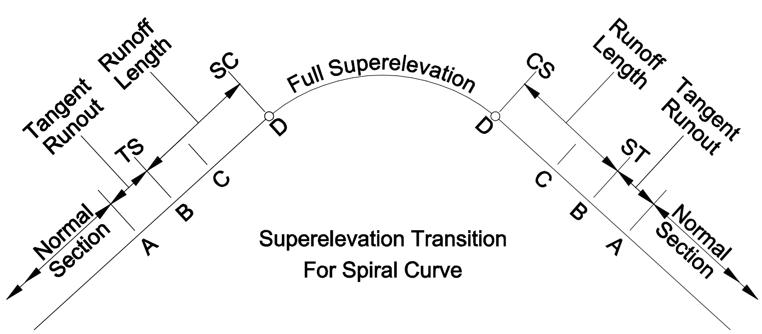
Once the superelevation runoff and tangent runout have been calculated or determined from Exhibits 3-5 through 3-7, the design team needs to determine how to fit the length in the horizontal and vertical planes. Exhibit 3-9 illustrates the application of the transition length in the plan view for both rural and urban roadways. See Section 3.3.5 for illustrations in the profile and cross section views. The following will apply:

1. **Spiral Curves.** The tangent runout (*TR*) will be placed on the tangent sections immediately before and after the spiral sections of the horizontal curve. The superelevation runoff (*L*) length at the beginning of the curve will begin at the point of tangent to spiral (*TS*) and end at the point of spiral to circular curve (*SC*). The application of *L* to the end of the curve will be from the curve to spiral (*CS*) to the spiral to tangent (*ST*). This means the length of the spiral curves are set equal to the superelevation runoff length.
2. **Circular Curves.** Typically, 70 percent of the superelevation runoff length will be placed on the tangent and 30 percent on the curve. For resurfacing and widening projects, it is acceptable to match the existing distribution of the superelevation runoff between the tangent and curve sections, even if 100 percent of the runoff length is on the tangent.

Exhibit 3-9
Application of Transition Length (Plan View)

Note: See Section 3.3.5 for profile and cross section views (Points A, B, C, D, and E) of superelevation development. Point C is the first (or last) point at which the cross section has a uniform slope





3.3.5 Axis of Rotation

The design team should prepare profiles along the roadway edges, top back of curb, and/or ditch flow lines to confirm ponding will not be an issue.

Superelevation axis of rotation should typically be about the centerline profile (Method A below) for all rural or urban roadways, except for those roadways with a median more than 10 feet wide. One of AASHTO Cases I to III should be applied, as described below, for roadways with a median more than 10 feet wide. Drainage should be carefully considered in the application of superelevation and the determination of axis of rotation. When one side of the roadway drops, this may lead to ponding along the inside of the curve. Additionally, blockages in ditch flow can occur, particularly if one side of the roadway is raised above centerline.

3.3.5.1 Roadways without a Median

Method A, axis of rotation about the centerline profile, is the preferred rotation method for all rural or urban roadways without a median.

Rural or urban roadways without a median should typically be rotated according to Method A; these include roadways with no median, flush medians, or raised medians 10 feet wide or less (see Case I in Section 3.3.5.2). Method A rotates the traveled way about the centerline profile of the traveled way. The centerline profile remains fixed while the inside-edge profile is dropped below the centerline and the outside-edge profile is raised above the centerline, thus creating the least amount of distortion to the edge of the roadway. This is the most widely used and adaptable method according to AASHTO. See Exhibits 3-10 and 3-11 for illustrations of Method A rotation for circular curves and spiral curves, respectively.

Methods B through D are described further in Appendix G. Use of any of these methods should be documented in the Alignment and Grade Review Report.

Method B, rotation about the inside-edge profile, was MDT's previously preferred axis of rotation method, but should now only be applied in special or unique circumstances. Method C, rotation about the outside-edge profile, and Method D, straight cross slope rotated about the outside-edge profile, are additional axis of rotation methods that are also only to be applied in special or unique circumstances.

In urban conditions, the axis of rotation is typically about the centerline of the traveled way (Method A). This means, for example, if on-street parking is present on only one side, the axis of rotation will not be in the center of the roadway section. Urban conditions may also present special cases because of the presence of two-way left-turn lanes, turning lanes at intersections, and other unique circumstances. For these situations, where superelevated, the axis of rotation should be determined on a case-by-case basis.

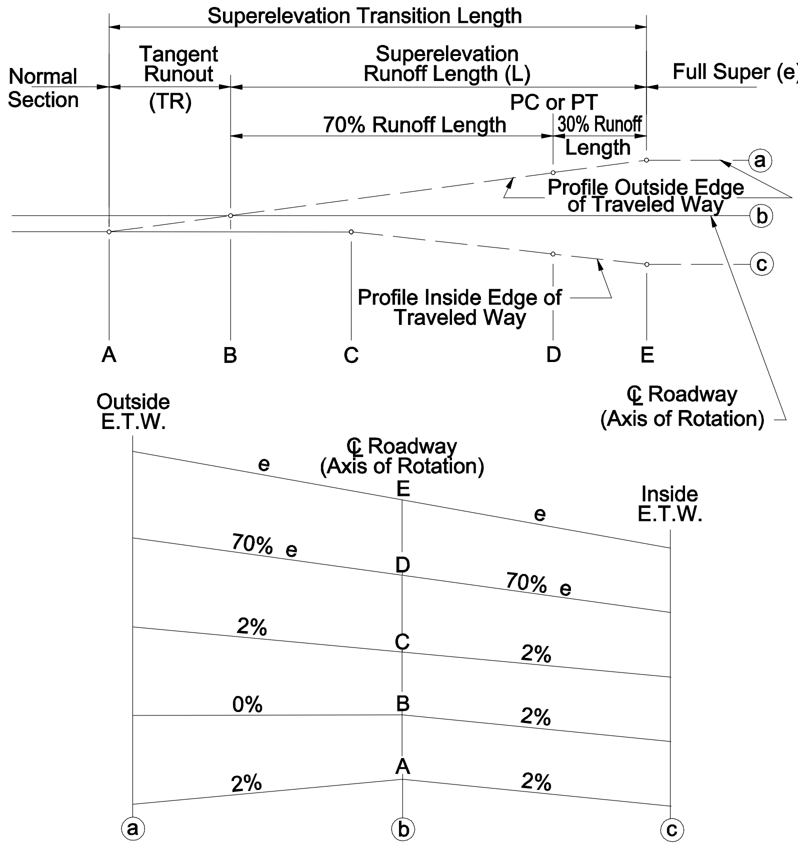
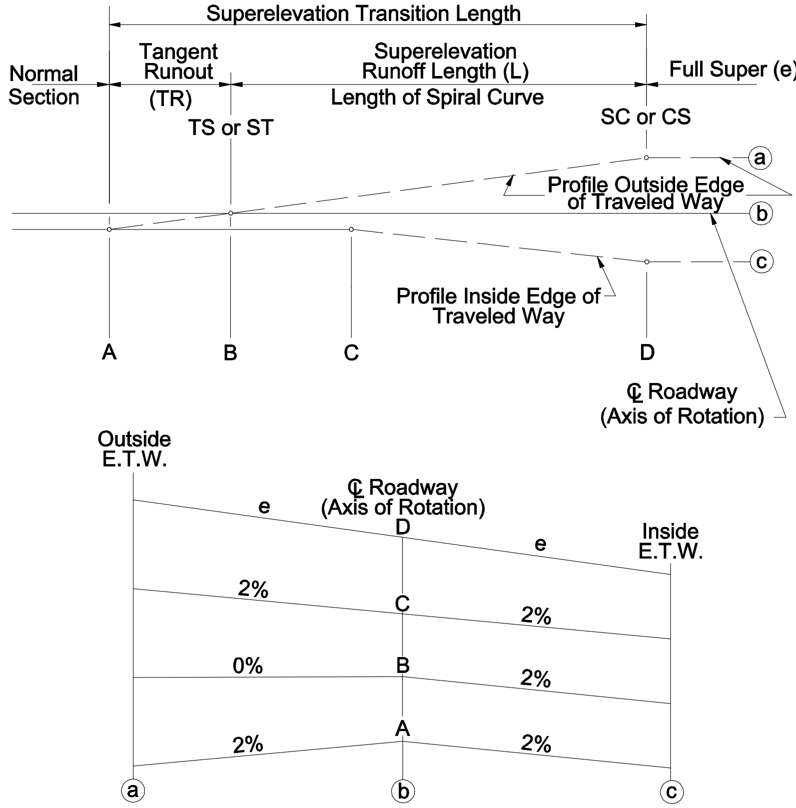


Exhibit 3-10
Axis of Rotation about Centerline Profile (Method A, Circular Curve)

Note: See Exhibit 3-9 for Plan View Illustration

Exhibit 3-11
Axis of Rotation about Centerline Profile (Method A, Spiral Curve)

Note: See Exhibit 3-9 for Plan View Illustration



3.3.5.2 Roadways with Medians

Exceptions to the location of the superelevation axis of rotation for roadways with medians may be necessary, particularly under urban conditions.

Rural or urban roadways with medians should typically be rotated according to AASHTO Cases I to III as described below:

- **Case I – Narrow Medians (≤ 10 feet wide):** The whole of the traveled way, including the median, is rotated as a plane section about the centerline profile, similar to Method A described above. Use of Case I should be limited to narrow medians less than 10 feet wide (may be applied with medians up to 15 feet wide if appropriate given the context) and moderate superelevation rates to avoid substantial differences in elevation of the extreme edges of the traveled way arising from the median tilt.
- **Case II – Medians >10 feet to 76 feet wide:** The median is held in a horizontal plane, and the two traveled ways are rotated separately about the median-edge of pavement. By holding the median edges level, the difference in elevation between the extreme edges of the traveled way can be limited to that needed to superelevate the roadway. See Exhibits 3-12 and 3-13 for illustrations of Case II rotation for circular curves and spiral curves, respectively.
- **Case III – Wide Medians (> 76 feet wide):** The two traveled ways are treated independently, with each typically being rotated about its respective centerline profile. The differences in elevation of the extreme edges of the traveled way are minimized by a compensating slope across the median.

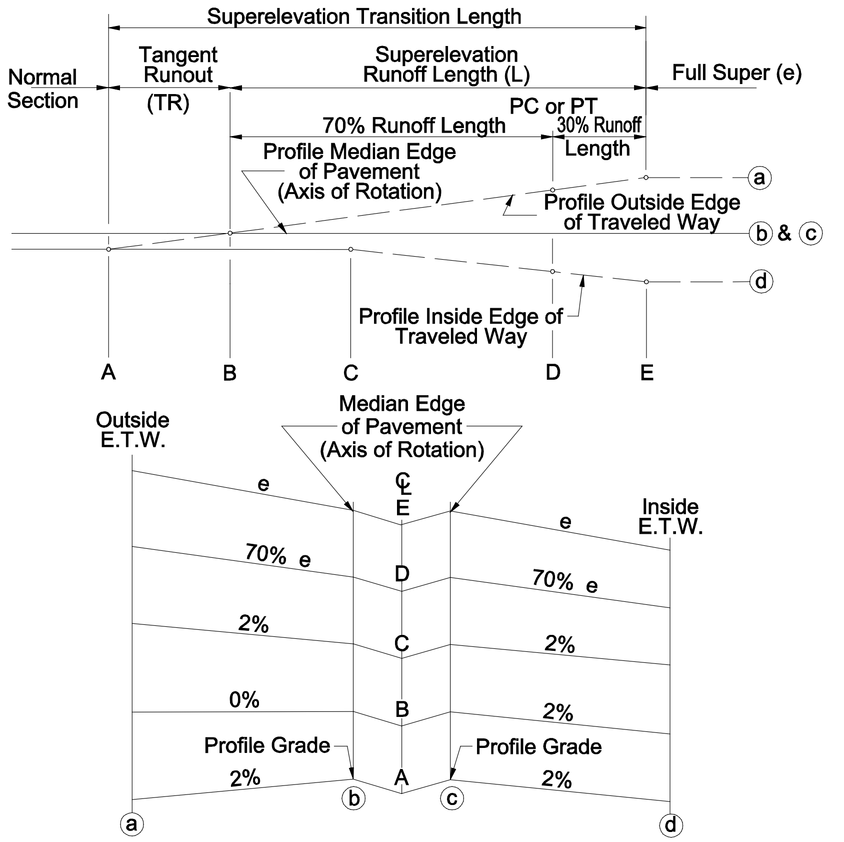


Exhibit 3-12
Axis of Rotation about Median-Edge of Pavement
(AASHTO Case II, Circular Curve)

Note: See Exhibit 3-9 for Plan View Illustration

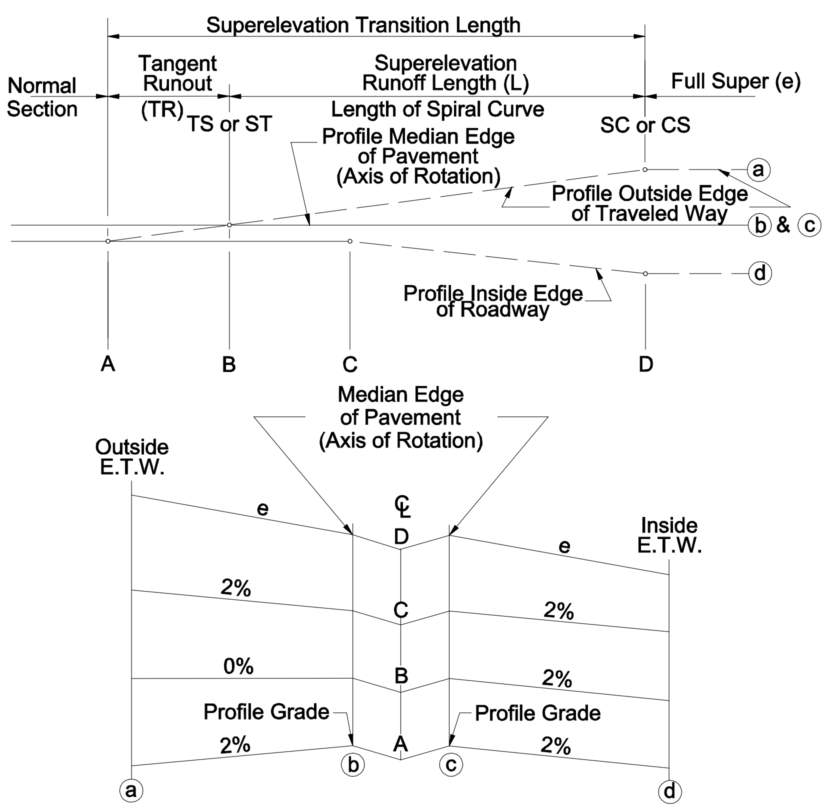


Exhibit 3-13
Axis of Rotation about Median-Edge of Pavement
(AASHTO Case II, Spiral Curve)

Note: See Exhibit 3-9 for Plan View illustration

3.3.6 Shoulder Superelevation

The typical application for shoulder superelevation is to rotate the shoulder concurrently with the adjacent travel lane; that is, the shoulder and travel lane remain in a plane section throughout the superelevated curve. This applies to superelevated sections on both rural and urban roadways.

This allowance may be necessary to meet roadside development constraints.

An allowance for the high side is to slope the shoulder such that the algebraic difference between the shoulder and adjacent travel lane does not exceed 8 percent (referred to as superelevation rollover). This rollover also applies to lanes which diverge from the mainline, such as ramps, and intersecting roadways.

For the low side, the portion of the subgrade from a point below the finished shoulder to the subgrade shoulder point is designed using a 2-percent slope, regardless of the superelevation of the traveled way. See the typical section figures in Chapter 5, Section 5.6 for illustrations.

3.3.7 Reverse Curves

Reverse curves are two closely spaced horizontal curves with deflections in opposite directions. When feasible, a normal crown tangent section of roadway should be provided between the curves. However, if superelevation transition requirements cannot be met to achieve a normal crown section for at least twice the tangent runout (*TR*) distance between the two curves, the roadway should be continuously rotated in a plane about the defined axis of rotation (typically the centerline profile). The relative longitudinal slope should remain consistent throughout the reverse curves if a continuously rotated plane is used.

The design team should adhere to the applicable superelevation transition lengths, where practical, for each curve. The minimum distance between the PT and PC of reverse circular curves should be the sum of 70-percent of the required runoff length for each of the two curves where practical.

If the minimum distance between the PT and PC cannot be achieved, the design team should document the specific application of the runoff length in the Alignment and Grade Review Report.

Exhibit 3-14 provides a schematic illustration of a transition to a normal crown section between circular reverse curves. The transition is the same between reverse spiral curves except the superelevation runoff lengths occur entirely on the spirals between the two curves (CS1 to ST1 and TS2 to SC2). Exhibit 3-15 provides a schematic illustration of a continuously rotating plane through circular reverse curves. The transition is the same between reverse spiral curves except the superelevation runoff lengths are applied to the spirals and tangent between the two curves (CS1 to SC2). See Appendix K for examples of the application and calculation of reverse curves.

Exhibit 3-14 Superelevation of Reverse Curves - Transition to Normal Crown between Curves

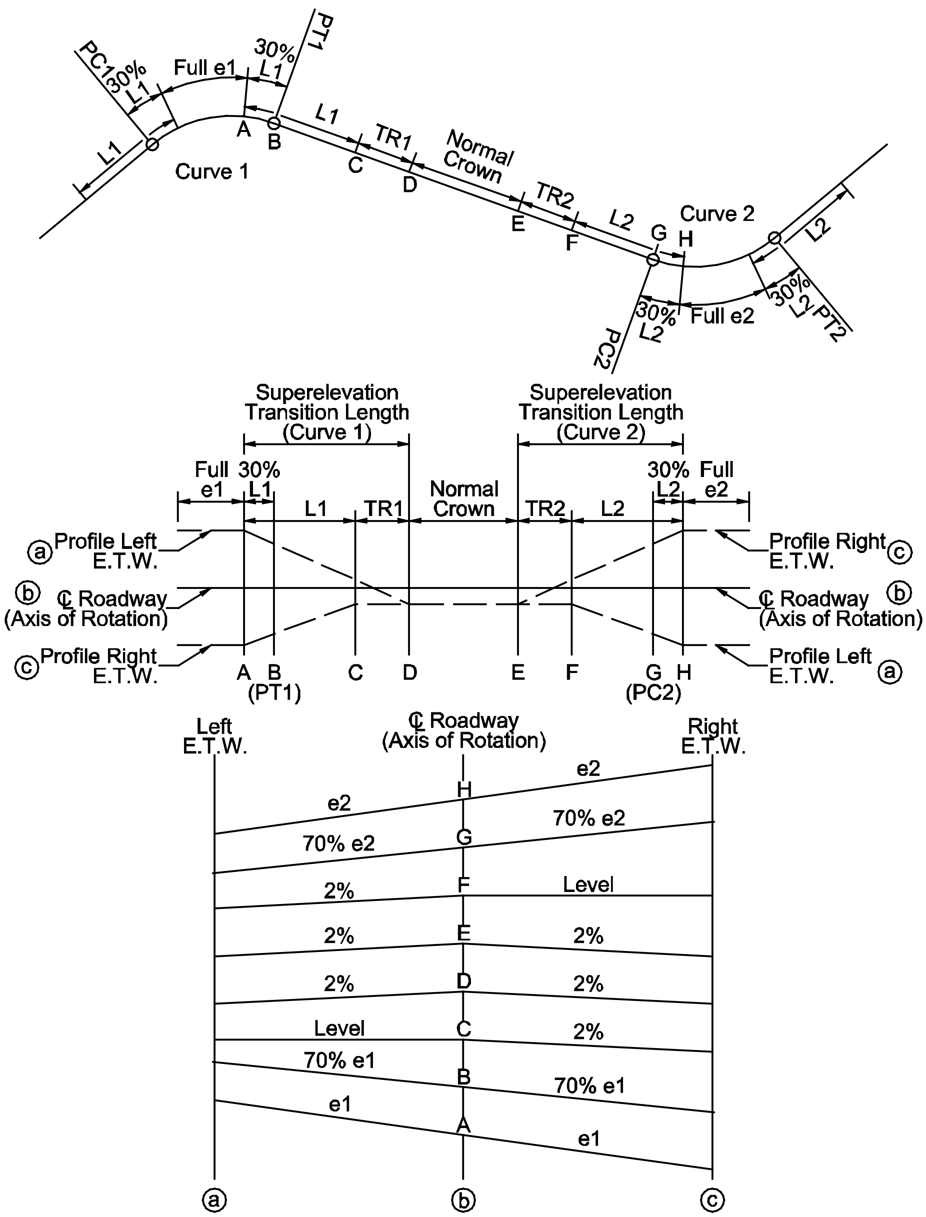
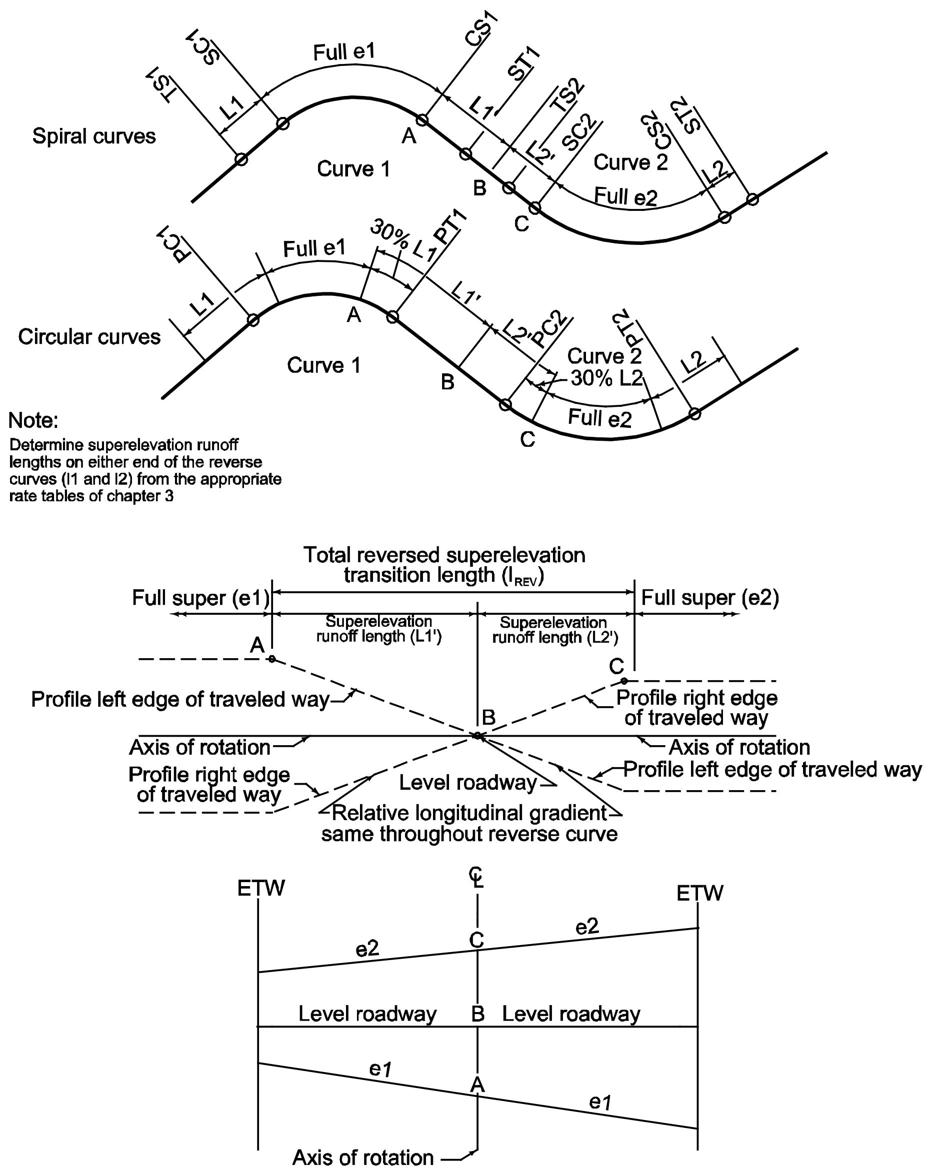


Exhibit 3-15 Superelevation of Reverse Curves - Continuously Rotating Plane



3.3.8 Broken-Back Curves

Avoid the use of broken-back curves where practical.

Broken-back curves are two closely spaced horizontal curves with deflections in the same direction and a short, intervening tangent. Where broken-back curves are used, the following will apply:

1. **Normal Crown Section.** The design team should not attempt to achieve a normal tangent section between broken-back curves unless the superelevation transition requirements can be met for both curves and at least 200 feet of normal crown section can be achieved.
2. **Superelevated Section.** If 200 feet of normal crown section cannot be achieved, the design team should provide a transitional curve-to-curve spiral, compound curve, or tangent connection to accommodate the gradual change between superelevation rates. This section should transition down from the first curve and back up to the second curve such that the rate of superelevation transition matches the standard value and a constant, lesser superelevation is maintained for at least 200 feet between the curves.

See Appendix K for examples of the application and calculation of broken-back curves.

3.3.9 Compound Curves

Compound curves are undesirable on Rural State Highways and High-Speed Urban Roadways except in transitional areas.

Compound curves are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other. Compound curves are most commonly used for transitioning low-speed roadways at intersections (for example, ramps, slip lanes), but can also be used on the mainline of low-speed urban roadways, particularly as a practical design alternative to spiral transitions. The design team should avoid a curve radius misleading the motorist's expectation of the sharpness of another curve radius within the compound curve. Therefore, compound curves on the mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve ($R_1 \leq 1.5R_2$, where R_1 is the flatter curve). Superelevation transition lengths can be applied to the approaching and leaving curves in the same manner as applied to single curves. See Appendix K for examples of the application and calculation of compound curves.

3.3.10 Bridges

From the perspective of the roadway user, a bridge is an integral part of the roadway system and, ideally, horizontal curves and their transitions will be located irrespective of their impact on bridges. However, safety considerations and practical factors in bridge design and bridge construction warrant consideration in the location of horizontal curves at bridges. The following presents, in order from the most desirable to the least desirable, the application of horizontal curves to bridges:

1. The most desirable treatment is to locate the bridge and its approach slabs on a tangent section and sloped at the typical cross slope; that is, no portion of the curve or its superelevation development is on the bridge or bridge approach slabs.

For #2, transitions are completed off of the bridge prior to Section D (spiral curve) and Section E (circular curve) in Exhibit 3-9.

2. If a bridge is located within a horizontal curve, transitions should not be located on the bridge or its approach slabs. This includes both superelevation transitions and spiral transitions. This will result in a uniform cross slope (the design superelevation rate) and a constant rate of curvature throughout the length of the bridge and bridge approach slabs.

For #3, transitions are completed off of the bridge prior to Section C (for both spiral and circular curves) in Exhibit 3-9.

3. If the superelevation transition is located on the bridge or its approach slabs, the design team should place on the roadway approach that portion of the superelevation development, which transitions the roadway cross section from its normal crown to a point where the roadway slopes uniformly, that is, there is no break in the cross slope on the bridge deck. This will avoid the need to warp the crown on the bridge or the bridge approach slabs.

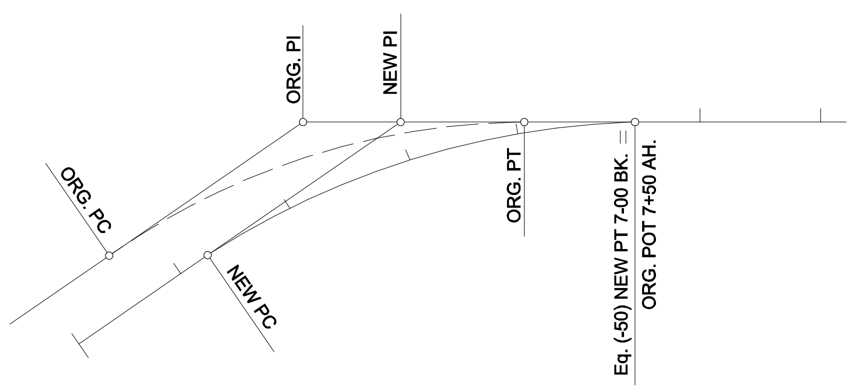
3.4 STATION EQUATIONS

If back station > ahead station, equation is (+). If back station < ahead station, equation is (-).

The following will apply to the use of equations in project stationing:

1. **Purpose**. An equation is used to equate two station numbers: one that is correct when measuring on the line before the equation, and one that is correct when measuring on the line after the equation. Equations should be used where stationing is not continuous throughout a project. Station equations should be avoided where possible on new roadway alignments.
2. **Locations.** Equations should be computed where the new design line become coincident with the original design line. This situation is illustrated in Exhibit 3-16.

Exhibit 3-16
New Design Line Becomes Coincident With Original Design Line



The design team should refer to Chapter 12 – Plan Preparation for details on indicating station equations throughout the road plans. It should be noted that (−) equations will not result in duplicate stationing, but (+) equations may result in duplicate stationing. The design team should attempt to avoid duplicate stationing when possible and be aware of the problems that can occur with duplicate stationing. For large (+) alignment changes, it may be necessary to add a large (−) equation at the point of divergence so that stationing is not duplicated.

3.5 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.
2. Ray, B., E. Ferguson, J. Knudsen, and R. J. Porter. *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets.* Transportation Research Board of the National Academies, Washington, D.C., 2014.
3. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 2011.
4. FHWA. *Manual on Uniform Traffic Control Devices (MUTCD)*. FHWA, Washington, D.C., 2009.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 4

Vertical Alignment

September 2016

Contents

Chapter 4

Vertical Alignment

The roadway vertical alignment plays a significant role in a roadway's safety, aesthetics and project costs. This chapter provides guidance on vertical alignment elements, including: coordination with other design elements, laying out a profile grade line, guidance on grades including maximum and minimum allowable grades, principles and application of vertical curves, and minimum vertical clearances. The *Montana Department of Transportation (MDT) Geometric Design Standards* provides specific vertical alignment standards relative to a roadway's functional classification *(1)*. Example calculations and detailed definitions associated with this chapter can be found in Appendix K.

4.1 DESIGN PRINCIPLES AND APPROACH

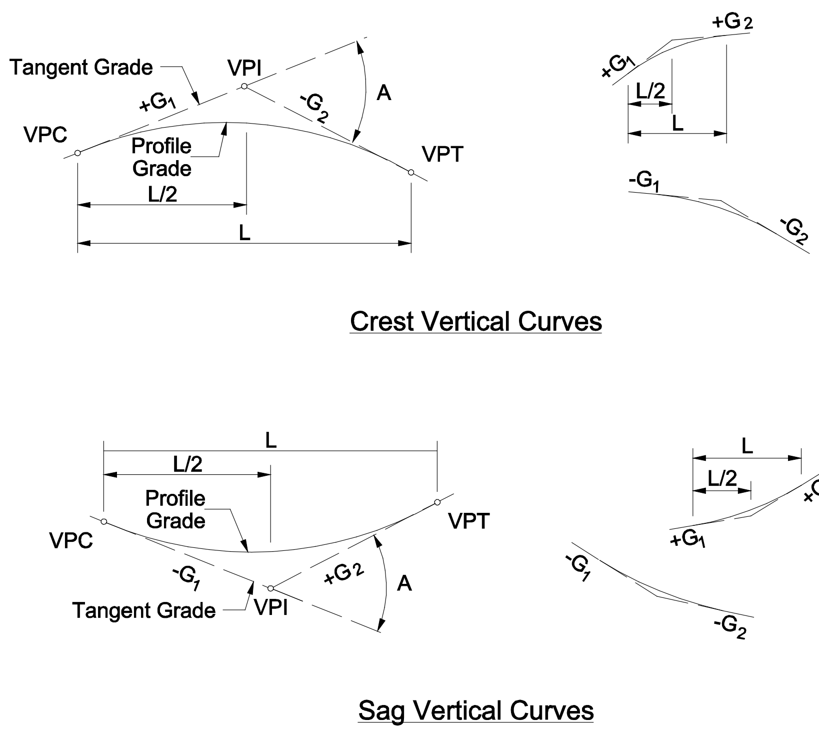
The design of vertical alignment, similar to horizontal alignment, involves a clear understanding of the design controls and criteria. These include maximum and minimum allowable grades, sight distance, and vertical clearances. In addition, the design team should be aware of how the vertical alignment impacts other design elements and the overall safety and aesthetic appearance of the roadway.

Determination and design of appropriate vertical tangent lengths, gradients, and crest and sag vertical curves form the basis of vertical alignment design. The gradient represents the slope between two adjacent vertical points of intersection and is most commonly expressed as a percentage. Vertical curves used to effect gradual changes between tangent grades consist of two types, sag and crest, and can either be symmetrical or asymmetrical. Exhibit 4-1 illustrates generic crest and sag vertical curves and identifies key elements such as the Tangent Grades (G_1 and G_2), the Length of Vertical Curve *(L)*, the Vertical Point of Curvature *(VPC)*, the Vertical Point of Intersection *(VPI)*, the Vertical Point of Tangency *(VPT)*, and the algebraic difference in grades *(A)*.

A performance-based road design approach, as described in Chapter 1, Section 1.2, can help the design team make decisions regarding K-value criteria.

Minimum lengths of crest or sag curves at various design speeds are commonly defined by the K-value, which represents the horizontal distance needed for a vertical curve to produce a 1-percent change in gradient. Minimum K-values relate lengths of vertical curves to required sight distance on crest curves and to headlight beam distance on sag vertical curves. The design team should consider various options to satisfy sight distance criteria on vertical curves. The design team should also understand that in some instances minimum stopping sight distance can be met without satisfying the minimum K-value.

Exhibit 4-1 Schematic of Vertical Alignment Curves



4.1.1 Coordination with Other Design Elements

The design of a vertical alignment must be coordinated with other design elements to ensure a safe, context-sensitive, and cost-effective design. The design elements to be considered when laying out a vertical alignment include:

1. **Consistency.** Use a smooth grade line with gradual changes, consistent with the type of roadway and character of terrain, rather than a line with numerous breaks and short lengths of tangent grades.
2. **Long Grades**. On a long ascending grade, it is preferable to place the steepest grade at the bottom and flatten the grade near the top.
3. **Intersections**. Maintain moderate grades through intersections to facilitate turning movements. See Chapter 6, Section 6.1.3 for specific information on vertical alignment through intersections.
4. **Broken-Back Curvature.** "Broken-back" grade lines (two vertical curves in the same direction separated by a short section of tangent

grade) should be avoided where feasible. One long vertical curve is more desirable.

5. **"Roller Coaster".** A "roller coaster" type of profile may be an outcome of fitting an alignment across varying topography; however the design team should avoid excessive ups and downs, which may be unpleasant aesthetically and difficult for drivers to navigate.
6. **Vertical Point of Intersection (VPI) Locations**. Set VPI locations at even 5-foot stations if practical.
7. **Environmental Impacts**. The vertical alignment should be properly coordinated with impacts to potential environmental resources and other natural resources, for example, encroachment onto wetlands.
8. **Consideration of Natural/Man-Made Features**. The vertical alignment should take into consideration the natural topography, available right-of-way, utilities, roadside development, structures, and natural or man-made drainage features.
9. **Drainage.** See Section 4.2.8 for drainage aspects to consider when establishing a vertical alignment.

4.1.2 Sight Distance Considerations

Two key considerations in the establishment of a vertical alignment are stopping sight distance and passing sight distance.

1. **Stopping Sight Distance.** All vertical curves must be designed to provide at least the stopping sight distance shown in Chapter 2, Exhibits 2-2 or 2-3. Additional stopping sight distance should be provided when practical. Determining the minimum length of a crest vertical curve using stopping sight-distance criteria typically results in a curve that is satisfactory from a safety, comfort, and appearance standpoint. Stopping sight distance for sag vertical curves at an undercrossing should also be considered. Outside of this condition, sight distance for sag vertical curves is provided as long as the design allows the vehicular headlights to illuminate the roadway surface. Sight distance on a roadway through a grade separation should be at least as long as the minimum stopping sight distance and where practical, even longer. Sections 4.4.1 and 4.4.2 and Chapter 2, Section 2.8.1.2 provide additional information for determining stopping sight distance for vertical curves.
2. **Passing Sight Distance.** At some locations, it may be desirable to provide passing sight distance in the design of crest vertical curves. On rural reconstruction projects, the design team should attempt to provide passing sight distance over as much of the roadway length as practical. It will generally not be cost-effective, however, to make significant improvements to the horizontal and vertical alignment solely to increase the available passing sight distance. Chapter 2, Section 2.8.3 discusses the application and design values for passing sight distance.

4.1.3 Coordination of Horizontal and Vertical Alignment

Chapter 2 provides additional guidance on performance based design and context sensitive principles that should be applied in the establishment and coordination of horizontal and vertical alignments.

Horizontal and vertical alignments should be designed in coordination, especially for projects on a new alignment. The design team should carefully evaluate the interdependence of these two roadway design features to enhance the roadway's safety and improve its operation. The following should be considered in the coordination of horizontal and vertical alignment:

1. **Balance.** The horizontal curvature and vertical grades and curves should be in proper balance. Over-emphasizing one or the other may lead to an unbalanced design. A compromise between the two extremes typically produces the best design relative to safety, operations, ease of driving, and uniformity of operations and aesthetics.
2. **Coordination**. Locating vertical and horizontal points of intersection (PIs) at approximately the same station generally results in a more pleasing appearance and reduces the number of sight distance restrictions. Successive changes in profile that are aligned with similar changes in horizontal curvature results in a series of humps visible to the driver for some distance, which may produce an unattractive design. However, coordination of the horizontal and vertical alignment should be tempered under conditions for crest and sag vertical curves described as follows.
    a. **Crest Vertical Curves.** Sharp horizontal curvature should not be introduced at or near the top of pronounced crest vertical curves. This is undesirable because the driver cannot perceive the horizontal change in alignment, especially at night when headlight beams project straight ahead into space. This problem can be avoided if the horizontal curvature occurs prior to the vertical curvature or by using curve design values exceeding minimums.
    b. **Sag Vertical Curves.** Sharp horizontal curves should not be introduced at or near the low point of pronounced sag vertical curves or at the bottom of steep vertical grades. Because visibility to the road ahead is foreshortened, only flat horizontal curvature will avoid an undesirable, distorted appearance. At the bottom of long grades, vehicular speeds often are higher, particularly for trucks, and erratic operations may occur, especially at night.

Additional information on passing sight distance is provided in Chapter 2, Section 2.8.3.

Chapter 6 provides additional design considerations for intersections.

3. **Passing Sight Distance.** In some cases, the need for frequent passing opportunities and a higher percentage of passing sight distance may supersede the desirability of combining horizontal and vertical alignment. In these cases, it may be necessary to provide long tangent sections to ensure sufficient passing sight distance.
4. **Intersections**. At intersections, horizontal and vertical alignments should be as flat as practical to provide sufficient sight distance and gradients for vehicles to slow or stop and to provide accessible cross slopes for people walking or using mobility aids.

5. **Divided Highways.** On divided highways with wide medians, it is typically advantageous to provide independent alignments for the roadway on each side of the median.
6. **Residential Areas.** Design the alignment to minimize nuisance factors, such as noise and visual pollution, to neighborhoods. Minor adjustments to the horizontal or vertical alignment or both may increase the buffer zone between the roadway and residential areas.
7. **Access.** Existing and proposed public and private approaches should be evaluated when coordinating horizontal and vertical alignment to ensure minimum intersection sight distance requirements are met.
8. **Drainage.** See Section 4.2.8 for drainage aspects to consider when coordinating horizontal and vertical alignment.
9. **Aesthetics.** The design team should always be mindful of, and work within, existing topographic and infrastructure constraints when establishing alignments. Where feasible and other constraints are not present, design the alignment to enhance attractive scenic views of rivers, rock formations, parks, or other features.

Stakeholder outreach early in the project development process can help identify critical features that should be considered throughout the design.

4.2 PROFILE GRADE LINE

The profile grade line is defined by a series of tangents connected by parabolic vertical curves, as needed. The profile grade line impacts a roadway's costs, aesthetics, safety, and operations. Design considerations for establishing the profile grade line are discussed below.

4.2.1 Profile Grade Line Locations

The location of the profile grade line on the roadway cross section varies according to the roadway type, whether or not the roadway is divided or undivided, and by the median type. The profile grade line locations are shown in the typical cross section exhibits provided in Chapter 5, Section 5.6. The recommended locations for profile grade lines and axes of rotation for various typical sections are provided below.

Exceptions to the location of the superelevation axis of rotation may be necessary to better fit the existing topography and other constraints and/or to provide for improved drainage.

1. **Roadways with Narrow Medians (≤ 10 feet wide).** For roadways with narrow medians (flush or raised), there is typically only one profile grade line at the centerline of the median or traveled way. A single profile grade line may be used for medians up to 15 feet in width if appropriate given the context. Typically, the superelevation axis of rotation is at the profile grade line at the centerline.
2. **Roadways with Medians ≥ 10 feet to 76 feet wide**. For roadways with medians (flush, raised, or depressed) in this range of widths, a profile grade line should typically be provided for each roadway and be established on the median edge of pavement. Typically, the superelevation axes of rotation are at the median edge of pavement profile grade lines.
3. **Roadways with Medians > 76 feet wide.** Roadways with wide medians typically use independent alignments for each direction of travel and are

treated as two separate roadways. Therefore, a profile grade line is necessary for each roadway and is typically provided at the centerline of each traveled way. Typically, the superelevation axes of rotation are at the centerline profile grade lines.

4. **Two-Lane Rural Highways.** For two-lane rural highways, there is typically only one profile grade line at the centerline of the traveled way. Typically, the superelevation axis of rotation is at the profile grade line at the centerline.
5. **Curbed Roadways**. For curbed roadways, follow the guidance provided in items 1-4 above depending on the median condition. In addition, separate profiles at the top back of curb should be provided where necessary to ensure positive drainage and to match existing development.

4.2.2 Urban Grade Design

Chapter 8, Section 8.4 provides additional design considerations for urban areas.

Laying out profile grade lines in urban areas often is more challenging due to limited right-of-way, closely spaced intersections, the need to meet existing roadside development, and drainage. The following provides several considerations that should be reviewed when developing a profile grade line on an urban project:

1. **Vertical Curves**. Long vertical curves on urban roadways are generally impractical. The design team will typically need to lay out the profile grade line to meet existing conditions. Therefore, no minimum vertical curve lengths are specified for urban roadways; however, the design team must ensure minimum sight distance criteria are satisfied and that design principles outlined in Section 4.1 are taken into consideration. Where practical, VPIs should be located at or near the centerlines of cross streets. In addition, at signalized and stop-controlled intersections some flattening of the approaches may be desired to allow vehicles to more easily pull away from a stopped position and to provide accessible cross slopes for people walking or using mobility aids.
2. **Drainage**. Urban roadways will often have curbs, which may complicate the layout of the profile grade to facilitate drainage. Reference Section 4.2.8 for additional guidance on drainage considerations when establishing profile grade lines on urban roadways.
3. **Spline Curves**. A spline curve is a curve connecting specific points, such as elevation points. Spline curves can be helpful in establishing profile grade lines in urban areas where it is necessary to meet numerous elevation restrictions in relatively short distances. Spline curves may also be used when developing profiles for the top of curbs. Show elevations along spline curves at 10-foot intervals.
4. **Earthwork Balance.** In general, balancing of earthwork is typically impractical in urban areas. An excess of excavation is preferable to the need for borrow due to the generally higher cost of borrow in urban areas.

5. **Limited Right-of-Way**. Careful consideration should be given when substantially lowering or raising the profile grade line. This can result in more right-of-way impacts and access issues (for intersecting roadways and adjacent property) along urban roadways.

4.2.3 Earthwork Balance/Soil Conditions

Where practical and consistent with other project objectives, design the profile grade line to provide a balance of earthwork. This should not be achieved, however, in a way that inhibits smooth grade lines and sight distance requirements at vertical curves. Ultimately, a project-by-project assessment will determine whether a project will require borrow, have excess material, or be balanced.

The type of earth material encountered often influences the profile grade line at certain locations. If rock is encountered, for example, it may be more economical to raise the grade and reduce the rock excavation. Soils which are unsatisfactory for embankment or cause a stability problem in cut areas may also be determining factors in establishing a grade line. The presence of poor quality or saturated soils may also influence the profile grade line due to the extra expense associated with excavating or stabilizing these soils. In these situations, the design team should consider soil information from soil borings and cores in development of the profile grade.

Avoidance of poor quality or saturated soils is often times more cost effective than balancing earthwork.

4.2.4 Field Constraints

Special grade control may be necessary across flats, lake beds, sloughs, creek bottoms, important intersecting roads, in front of improved property, at places subject to snow drifting, and at other places requiring special attention. The design team should review and consider these recommendations when establishing the profile grade line.

Any areas requiring special grade control should be identified at the Preliminary Field Review and alternatives should be discussed.

4.2.5 Ties with Existing Roadways/Adjoining Projects

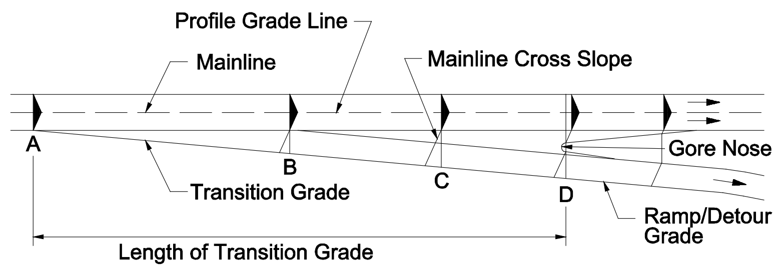
A smooth transition is needed between the proposed profile grade line of the project and the existing grade line of an adjacent roadway section, or in some cases the proposed grade line for an adjacent project. Based on road classification and project context, profile grade lines should be reviewed beyond the beginning and end of a project to ensure adequate sight distance and proper conformance with existing profile grades. Connections to existing roadway approaches should be compatible with the design speed of the new project and fit the overall context of the corridor.

4.2.6 Transition Grades

Transition grades are used where a roadway alignment diverges from or merges into the mainline alignment; examples include freeway ramps, turning roadways, and detours. Exhibit 4-2 illustrates the location of the transition grade for ramps and detours. The transition grade is the profile grade line where the taper from the mainline begins (section “A” on Exhibit 4-2) to the point where the ramp or roadway grade becomes independent of the mainline (for example, at the gore nose, section “D” on Exhibit 4-2).

The transition grade is dependent on the mainline grade and cross slopes until the ramp or roadway becomes independent (Section "D" in Exhibit 4-2). For ramps, the transition grade should extend from the beginning of the taper of the ramp away from the mainline to a point where the distance between the outside shoulder of the mainline and the inside shoulder of the ramp is 8 feet. For detours, the transition grade should extend from the beginning of the taper from the mainline to a point where the distance between the outside shoulder of the mainline and the inside shoulder of the detour is 4 feet. Chapter 10 provides additional design consideration details for detours.

Exhibit 4-2
Transition Grade - Ramps/Detours



Site constraints may dictate the necessity for cross slope superelevation transition within the length of the transition grade. Also, ramps (and other turning roadways) that intersect mainline in superelevated sections, may require different cross slopes due to opposite directions of curvature or for difference in design speeds. For these cases, the cross slope of the ramp in the transition grade area may vary from the cross slope of the mainline to permit a transition to the appropriate superelevation/cross slope of the ramp. When the cross slope is different from that of the mainline, the transition grade is established through a spline curve (best fit curve) through elevations determined and shown at intervals of 10 to 20 feet. Developing separate spline curves for each edge of the ramp traveled way and the gore area is helpful in ensuring proper design and construction is achieved. The point elevations defining the spline curve should be determined with consideration to the following:

1. The grade and cross slope of the turning roadway should transition smoothly without abrupt changes.
2. The maximum relative longitudinal gradient criteria, adjusted for width should be met. See Section 3.3.4.
3. Drainage should be adequate to avoid ponding throughout the paved portion of the gore or spread width encroaching onto the traveled way.
4. The maximum algebraic difference in cross slope at the crossover crown line (points A to B) are limited as shown in Exhibit 4-3. Additional information can be found in the AASHTO Green Book *(2)*.

Design Speed of Exit or Entrance Curve (mph)	Maximum Algebraic Difference in Cross Slope at Crossover Crown Line (%)
20 and under	5.0 to 8.0
25 and 30	5.0 to 6.0
35 and over	4.0 to 5.0

Exhibit 4-3 Maximum Algebraic Difference in Cross Slope at Turning Roadway Terminals

4.2.7 Bridges and Drainage Structures

The design of profile grade lines should be carefully coordinated with any bridges or drainage structures within the project limits. The following will apply:

1. **Vertical Clearances.** Section 4.5 provides additional information on minimum vertical clearances. The criteria in Section 4.5 must be met where a new roadway and structure will be constructed over an existing roadway or where the roadway will be reconstructed under an existing bridge. When developing the preliminary profile grade line, an important element in determining available vertical clearance is the assumed structure depth. This will be based on the structure type, span lengths, and depth-to-span ratio. The design team should coordinate with the Bridge Bureau to obtain an estimated depth of structure or minimum profile elevation.
2. **Roadway Under Bridge**. Where practical, the low point of a roadway sag vertical curve under a bridge should not be in close proximity to the bridge. This will help minimize ice accumulations near and under the bridge, and it will reduce the ponding of water which may weaken the earth foundation beneath the bridge. To achieve these objectives, the low point of a roadway sag curve should be approximately 100 feet or more from the bridge.
3. **Bridges Over Water.** Where the proposed roadway will cross bodies of water, the bridge elevation must be consistent with the necessary waterway opening to meet MDT's hydraulic requirements. The design team provides the Bridge Bureau with the preliminary profile grade line and proposed cross section. The Bridge Bureau determines minimum bridge elevations based on the hydraulic requirements and structure type. Establishing grades for structures over drainage features can be an iterative process, requiring coordination between the hydraulic, roadway, and bridge design teams.

Grades of bridges over water should provide adequate drainage to bridge ends where barrier/curb is required on the structure.

4. **Bridges Over Railroads.** Any proposed roadways over railroads must meet the applicable criteria (e.g., vertical clearances, structure type and depth). See Section 4.5 for minimum vertical clearance criteria. The design team should contact the Bridge Bureau and the Utilities Section for more information.
5. **High Embankments.** The design team should consider the impacts of high embankments on structure lengths. A roadway alignment that creates high embankments will increase the span length, thus increasing structure costs.
6. **Bridge Decks**. Bridge deck drainage is often less efficient than the drainage on roadway sections and the spread of water on the deck is

often more difficult to control. This is primarily due to deck cross slopes that are often flatter, issues with debris build-up on the deck, and the inherent limitations of inlets placed on a bridge deck. Zero or relatively flat gradients and locating the low point of a sag vertical curve on the bridge deck should be avoided where feasible.

4.2.8 Drainage

The profile grade line should be compatible with the roadway drainage design. The design team should consider the following in the establishment of a profile grade line:

1. **Existing Drainage Patterns.** Strive to minimize interference with existing drainage patterns to the extent possible. If the redirection of existing flows is unavoidable, careful attention and consideration should be given to the impacts this may have on adjacent properties, flood control measures, and water quality control.
2. **Minimum Longitudinal Grades.** The profile grade line is important to consider on any roadway, but especially for shallow grades along curbed roadways.
   a. **Curbed Roadways.** The centerline profile on roadways with curbs should have a minimum longitudinal gradient of 0.5 percent where feasible. Longitudinal gradients less than 0.5 percent can be considered under special circumstances, but may require additional storm drain inlets or other special drainage treatments. Because surface drainage is retained within the roadway, special care should be taken to avoid flat spots where water may pond. Separate profile grade lines at the top back of curb should be developed when needed to ensure adequate drainage to inlets. Curb elevations should be designed to permit drainage flow into the gutter and to avoid ponding of water.
   b. **Shouldered Roadways**. Where feasible, a 0.5-percent minimum longitudinal grade should be provided to encourage drainage and avoid ponding in the ditches away from the planned low points. Longitudinal gradients that are level may be acceptable on pavements in fill areas with an adequate roadway crown to drain laterally. The minimum longitudinal grade in cut sections is 0.2 percent. Independent ditch grades should be provided to ensure adequate roadside drainage when minimum roadway grades cannot be provided.
3. **Vertical Curves.** Drainage should be considered in the design of vertical curves, especially where curbed sections are used. Drainage problems should not be experienced if the vertical curvature is pronounced enough that a minimum longitudinal grade of at least 0.3 percent is reached at a point about 50 feet from either side of the high or low point of the curve. To ensure this objective is achieved, the length of the vertical curve should be based upon a maximum K-value of 167 or less. For vertical curves on curbed sections where this K-value is exceeded, the drainage design should be more carefully evaluated near the high or

low point of the curve. Separate curb profiles resulting in varying cross slopes may be necessary to ensure adequate drainage and for sag vertical curves it may be necessary to install flanking inlets on either side of the low point.

4. **Intersections.** At intersections, the surface drainage should preferably be intercepted upstream of the intersection. Where surface drainage is provided across intersecting roadways, use of valley gutters should be considered.
5. **Culverts**. The roadway elevation should provide at least the minimum cover indicated in the culvert fill height tables in Chapter 11, Section 11.2. The top of culvert should be located below the top of the subgrade where feasible. The low points of a sag vertical curve should not be located directly above culverts where feasible. In the event that flooding overtops the roadway, culverts located at low points have a greater chance of being washed out. See Chapter 11 for additional information on culvert designs.

4.2.9 Snow Drifting

The profile grade line should minimize snow drift challenges. Where practical, the profile grade line should be at least 2 feet above the natural ground level on the windward side of the roadway to prevent snow from drifting onto the roadway and to promote snow blowing off the roadway. For cut sections, the use of wider ditches, flatter than standard backslopes, other drifting mitigation features (e.g., snow fence), or combinations thereof may be appropriate.

4.2.10 Erosion Control

To minimize erosion, the design team should consider the following relative to the grade line:

- Minimize the number of deep cuts and high fill sections;
- Conform to the contour and drainage patterns of the area;
- Make use of natural land barriers and contours to divert runoff and confine erosion and sedimentation;
- Minimize the amount of disturbance;
- Make use of existing vegetation;
- Reduce slope length and steepness to attempt to contain erosion within the right-of-way and not deposit sediment on or erode away adjacent land;
- Avoid locations having high erosion potential; and
- Avoid cut or fill sections in seepage areas, including areas with springs or a high water table.

Refer to the *MDT Permanent Erosion and Sediment Control (PESC) Manual* for additional information on erosion control.

4.2.11 Project Types

A new profile grade line should be shown for reconstruction projects, pavement pulverization projects, and projects that involve major surfacing rehabilitation. It will likely not be necessary to provide profile grade lines for pavement preservation or other minor surfacing rehabilitation projects.

4.3 GRADES

The use of maximum and minimum grades in a vertical alignment has an impact on the earthwork, sight distance, drainage, and other design related items. The critical length of grade and its impact on the vertical alignment design is also an important consideration.

4.3.1 Maximum Grades

The *MDT Geometric Design Standards* document presents criteria for maximum grades based on functional classification, type of terrain, and in some cases, design speed *(1)*. The maximum grades should be used only where necessary. Where practical, use grades flatter than the maximum.

4.3.2 Minimum Grades

Minimum grades are primarily determined based on drainage needs and requirements and are described in detail in Section 4.2.8.

4.3.3 Critical Length of Grade and Truck Climbing Lanes

The design team should coordinate with the Traffic and Safety Bureau to determine the critical length of grade.

The critical length of grade is the maximum length of a specific upgrade on which a loaded truck can operate without experiencing a specified reduction in speed. The roadway gradient in combination with the length of grade will determine the truck speed reduction on upgrades.

The Traffic and Safety Bureau will typically determine the need for truck-climbing lanes and will provide the design details for these lanes where they are warranted.

4.4 VERTICAL CURVES

Vertical curves should be simple in application and should result in a design enabling the driver to see the road ahead, enhancing vehicle control, pleasing in appearance, and adequate for drainage. On urban roadways, vertical curves are not required when the algebraic difference in grades is less than 1 percent. However, the use of vertical curves on urban roadways should be considered when the algebraic difference in grades is greater than 0.5 percent. Vertical grade breaks without curves are not allowed on rural roadways.

See Chapter 2, Section 2.8.1 for information and illustrations on checking sight distance on a plotted profile.

If a vertical curve is justified, the following sections outline criteria for laying out both crest and sag vertical curves. The discussion centers around the principle of providing adequate sight distance, which is commonly applied through a K-value, defined as the horizontal distance needed to produce a 1-percent change in gradient. The design team should recognize that adequate sight distance will be provided when a vertical curve is designed to meet or exceed the minimum K-value for a given design speed. However, adequate sight distance may still be provided even if the minimum K-value is not satisfied; this is particularly true for longer sight distance values. The design team can check sight distance on a plotted profile if in doubt.

4.4.1 Crest Vertical Curves

Crest vertical curves are in the shape of a parabola. The basic equations for determining the minimum length of a crest vertical curve are:

When S is less than L,

$$L = \frac{AS^2}{200(\sqrt{h_1} + \sqrt{h_2})^2}$$

Equation 4.4-1

When S is greater than L,

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

Equation 4.4-2

Note: For small values of *A*, calculated vertical curve lengths may be near zero because the sight line passes over the high point of the curve. In these cases, use Equation 4.4-5 to determine the minimum length of vertical curve.

Where:

L = length of vertical curve, feet

A = algebraic difference between the two tangent grades, percent

S = sight distance, feet

h_1 = height of eye above road surface, feet

h_2 = height of object above road surface, feet

The length of the crest vertical curve will depend upon the algebraic difference between two tangent grades for the specific curve, the selected sight distance, the height of eye, and the height of object. The following sections discuss the selection of these values. Equations 4.4-1 and 4.4-2 allow the design team to input different values for h_1 and h_2 to determine the length of vertical curve (L) based on the algebraic difference in grades (A) and required sight distance (S).

A basic assumption in the application of Equations 4.4-1 and 4.4-2 is that only one curve occurs within the required sight distance. Refer to Appendix F for discussion on sight distance influenced by multiple curves.

The application of Equations 4.4-1 and 4.4-2 may be an iterative process, as described below, depending on the calculated value of L.

1. Calculate an initial value of L based on Equation 4.4-1 and compare this value to the required value of S.
2. If S is less than L, then use the calculated value of L from Equation 4.4-1 for designing the crest vertical curve.
3. If S is greater than L, then recalculate L based on Equation 4.4-2 and use this recalculated value of L for designing the crest vertical curve.
4. For small values of A, calculated vertical curve lengths may be near zero because the sight line passes over the high point of the curve. In these cases, use Equation 4.4-5 to determine the minimum length of vertical curve.

Equations 4.4-1 and 4.4-2 can be reduced to Equation 4.4-3 by assuming a required sight distance and specific values for h_1 and h_2 based on the type of sight distance required (such as stopping sight distance or passing sight distance).

Equation 4.4-3

$$L = KA$$

Where:

L = length of vertical curve, feet

K = horizontal distance needed to produce a 1-percent change in gradient

A = algebraic difference between the two tangent grades, percent

Determining K-values for crest vertical curves is described in detail in the following sections. For design purposes, the calculated length of curve based on the rounded K-value should be rounded up to the next highest 50-foot increment where practical. Rounding to the next highest 10-foot increment is typically appropriate for urban roadways.

4.4.1.1 Minimum Stopping Sight Distance

Equation 4.4-4 assumes the typical values for h_1 and h_2, 3.5 feet and 2.0 feet, respectively, to calculate the K-value for crest vertical curves at different required sight distances. The values of K derived from Equation 4.4-4 (when S is less than L) also can be used without significant error where S is greater than L.

Equation 4.4-4

$$K = \frac{S^2}{2158}$$

Where:

K = horizontal distance needed to produce a 1-percent change in gradient

S = sight distance, feet

Unless both tangent grades are upward, the stopping sight distance for the downgrade condition will always control the crest vertical curve design.

The principal control in the design of crest vertical curves is to ensure that, at a minimum, stopping sight distance is provided throughout the curve. Short vertical curves are sometimes unavoidable in urban settings and may not meet minimum K-values, but may meet the required stopping sight distance if checked on a plotted profile.

Exhibit 4-4 presents minimum stopping sight distances for various downgrade conditions and the associated K-values for passenger cars on crest vertical curves. The values in Exhibit 4-4 are calculated using Equation 4.4-4. The minimum values represent the lowest acceptable sight distance on a roadway at a given downgrade; however, the design team should provide a design in which the K-values meet the greatest practical stopping sight distance.

Design Speed (V) (mph)	Stopping Sight Distances (ft)				K-Values[1] ($K=S^2/2158$)			
	Level[2] (<3%)	Downgrades			Level[2] (<3%)	Downgrades		
		3%	6%	9%		3%	6%	9%
15	80	80	82	85	3	3	4	4
20	115	116	120	126	7	7	7	8
25	155	158	165	173	12	12	13	14
30	200	205	215	227	19	20	22	24
35	250	257	271	287	29	31	35	39
40	305	315	333	354	44	46	52	59
45	360	378	400	427	61	67	75	85
50	425	446	474	507	84	93	105	120
55	495	520	553	593	114	126	142	163
60	570	598	638	686	151	166	189	219
65	645	682	728	785	193	216	246	286
70	730	771	825	891	247	276	316	368
75	820	866	927	1003	312	348	399	467
80	910	965	1035	1121	384	432	497	583

(1) K-values are calculated using rounded stopping sight distances, eye height of 3.5 feet and object height of 2 feet: $K=S^2/200(\sqrt{3.5}+\sqrt{2})^2$. The values of K derived from this equation (when S is less than L) also can be used without significant error where S is greater than L.
(2) The stopping sight distance for the "Level (<3%)" grades also applies to upgrades.

Exhibit 4-4
Stopping Sight Distances & Minimum K-Values for Crest Vertical Curves

Note: Refer to Equations 2.8-3 and 4.4-4 for calculating stopping sight distances and K-values for downgrades other than those shown in Exhibit 4-4. Interpolation between the values shown is not appropriate.

The steeper of the two gradients on either side of the crest vertical curve should be used in establishing the minimum stopping sight distance and K-value, except in the case of one-way roadways where the gradient in the direction of travel should be used.

4.4.1.2 Minimum Length of Curve (Rural Roadways)

Where the algebraic difference in grades (A) is small, the calculated curve lengths may be near zero (based on Equations 4.4-1 and 4.4-2). However, angle points are not allowed on rural roadways. Therefore, the minimum length of crest vertical curve is based on Equation 4.4-5.

MDT does not suggest a minimum length of crest vertical curve for urban roadways.

Equation 4.4-5

$$L_{min} = 3V$$

Where:

L_{min} = minimum length of vertical curve, feet

V = design speed, mph

4.4.1.3 Passing Sight Distance

At some locations, it may be desirable to provide passing sight distance in the design of crest vertical curves. On rural reconstruction projects, the design team should attempt to provide passing sight distance over as much of the roadway length as practical. However, making significant improvements to the horizontal and vertical alignments solely to increase the available passing sight distance will generally not be cost effective. Chapter 2, Section 2.8.3 discusses the application and design values for passing sight distance. These values of S are used in the basic equations for crest vertical curves (Equations 4.4-1 and 4.4-2). Equation 4.4-6 assumes the height of eye (h_1) is 3.5 feet, and the height of object (h_2) is also 3.5 feet. The values of K derived from Equation 4.4-6 (when S is less than L) also can be used without significant error where S is greater than L.

Equation 4.4-6

$$K = \frac{S^2}{2800}$$

Where:

K = horizontal distance needed to produce a 1-percent change in gradient

S = sight distance, feet

Exhibit 4-5 presents the minimum passing sight distances and the associated K-values for passenger cars on crest vertical curves.

Exhibit 4-5
Minimum K-values for Crest Vertical Curves - Passing Sight Distance

Design Speed (mph)	Minimum Passing Sight Distance For Design(1) (ft)	Calculated K-Values(2) ($K=S^2/2800$)	K-Values Rounded For Design(2)
20	400	57.1	57
25	450	72.3	72
30	500	89.3	89
35	550	108.0	108
40	600	128.6	129
45	700	175.0	175
50	800	228.6	229
55	900	289.3	289
60	1000	357.1	357
65	1100	432.1	432
70	1200	514.3	514
75	1300	603.6	604
80	1400	700.0	700

(1) Passing sight distances are from Chapter 2, Section 2.8.3.
(2) K-values are calculated using the passing sight distance, eye height of 3.5 feet, and object height of 3.5 feet: $K=S^2/200(\sqrt{3.5}+\sqrt{3.5})^2$. The values of K derived from this equation (when S is less than L) also can be used without significant error where S is greater than L.

4.4.2 Sag Vertical Curves

Sag vertical curves are also in the shape of a parabola. Typically, they are designed to allow the vehicular headlights to illuminate the roadway surface (i.e., the height of vehicular headlights is 2.0 feet and the height of object is 0.0 feet over a given distance *S*). These assumptions yield the following basic equations for determining the minimum length of sag vertical curves:

When S is less than *L*,

$$L = \frac{AS^2}{200h_3 + 3.5S}$$

Equation 4.4-7

When S is greater than L,

$$L = 2S - \frac{200h_3 + 3.5S}{A}$$

Equation 4.4-8

Note: For small values of A, calculated vertical curve lengths may be near zero. In these cases, use Equation 4.4-5 to determine the minimum length of vertical curve.

Where:

L = length of vertical curve, feet

A = algebraic difference between the two tangent grades, percent

S = sight distance, feet

h_3 = height of headlights above pavement surface, feet

The length of the sag vertical curve will depend upon the algebraic difference between two tangent grades for the specific curve, the selected sight distance, and headlight height. Equations 4.4-7 and 4.4-8 allow the design team to input a different value for h_3 to determine the length of vertical curve (*L*) based on the algebraic difference in grades (*A*) and required sight distance (*S*).

A basic assumption in the application of Equations 4.4-7 and 4.4-8 is that only one curve occurs within the required sight distance. Refer to Appendix F for discussion on sight distance influenced by multiple curves.

The application of Equations 4.4-7 and 4.4-8 may be an iterative process, as described below, depending on the calculated value of *L*.

1. Calculate an initial value of L based on Equation 4.4-7 and compare this value to the required value of *S*.
2. If S is less than *L*, use the calculated value of L from Equation 4.4-7 for designing the sag vertical curve.
3. If S is greater than *L*, recalculate L based on Equation 4.4-8 and use this recalculated value of L for designing the sag vertical curve.
4. For small values of *A*, calculated vertical curve lengths may be near zero. In these cases, use Equation 4.4-5 to determine the minimum length of vertical curve.

Equations 4.4-7 and 4.4-8 can be reduced to Equation 4.4-9 by assuming a required sight distance and a specific value for h_3 (headlight height).

$$L = KA$$

Equation 4.4-9

Where:

L = length of vertical curve, feet

K = horizontal distance needed to produce a 1-percent change in gradient

A = algebraic difference between the two tangent grades, percent

Determining K-values for sag vertical curves is described in detail in the following section. For design purposes, the calculated length of curve based on the rounded K-value should be rounded up to the next highest 50-foot increment where practical. Rounding to the next highest 10-foot increment is typically appropriate for urban roadways.

4.4.2.1 Minimum Stopping Sight Distance

Equation 4.4-10 assumes the typical value for h_3, 2.0 feet, to calculate the K-value for sag vertical curves at different required sight distances. The values of K derived from Equation 4.4-10 (when S is less than L) also can be used without significant error where S is greater than L.

Equation 4.4-10

$$K = \frac{S^2}{400 + 3.5S}$$

Where:

K = horizontal distance needed to produce a 1-percent change in gradient

S = sight distance, feet

The principal control in the design of sag vertical curves is to consider if, at a minimum, stopping sight distance (SSD) is provided for headlight illumination throughout the curve. The design assumes that there is a 1.0-degree upward divergence of the light beam from the longitudinal axis of the headlights.

Exhibit 4-6 presents minimum stopping sight distances for various downgrade conditions and the associated K-values for passenger cars on sag vertical curves. The values in Exhibit 4-6 are calculated using Equation 4.4-10. The minimum values represent the lowest acceptable sight distance on a roadway at a given downgrade; however, the design team should consider providing a design in which the K-values meet the greatest practical stopping sight distance.

Exhibit 4-6
Stopping Sight Distances & Minimum K-Values for Sag Vertical Curves

Note: Refer to Equations 2.8-3 and 4.4-10 for calculating stopping sight distances and K-values for downgrades other than those shown in Exhibit 4-6. Interpolation between the values shown is not appropriate.

Design Speed (V) (mph)	Stopping Sight Distances (ft)				K-Values(1) ($K=S^2/(400+3.5S)$)			
	Level (<3%)	Downgrades			Level (<3%)	Downgrades		
		3%	6%	9%		3%	6%	9%
15	80	80	82	85	10	10	10	11
20	115	116	120	126	17	17	18	19
25	155	158	165	173	26	27	28	30
30	200	205	215	227	37	38	41	44
35	250	257	271	287	50	51	55	59
40	305	315	333	354	64	67	71	77
45	360	378	400	427	79	83	89	97
50	425	446	474	507	96	102	110	119
55	495	520	553	593	115	122	131	143
60	570	598	638	686	136	144	155	169
65	645	682	728	785	157	167	180	196
70	730	771	825	891	181	192	208	226
75	820	866	927	1003	206	219	236	258
80	910	965	1035	1121	231	247	267	291

(1) K-values calculated using rounded stopping sight distances and a headlight height (h_3) of 2 feet: $K=S^2/((200*2.0)+3.5S)$. The values of K derived from this equation (when *S* is less than *L*) also can be used without significant error where *S* is greater than *L*.

The steeper of the two gradients on either side of the sag vertical curve should be used in establishing the minimum stopping sight distance and K-value, except in the case of one-way roadways where the gradient in the direction of travel should be used.

4.4.2.2 Minimum Length of Curve (Rural Roadways)

For most sag vertical curves on rural roadways, the minimum length of curve should be based on Equation 4.4-5 ($L_{min} = 3V$).

MDT does not suggest a minimum length of sag vertical curve for urban roadways.

4.4.3 Asymmetrical Vertical Curves

Occasionally, it is necessary to use an asymmetrical vertical curve to obtain clearance on a structure or to meet other field conditions. This curve is similar to the parabolic vertical curve, except the curve is not symmetrical about the VPI (different curve lengths on each side of the VPI). See Appendix K for examples of the application and calculation of asymmetrical vertical curves.

4.4.4 Vertical Curve Through a Fixed Point

A vertical curve sometimes must be designed to pass through an established point. For example, it may be necessary to tie into an existing transverse road or to clear existing structures. See Appendix K for examples of the application and calculation of a vertical curve through a fixed point.

4.5 MINIMUM VERTICAL CLEARANCES

Exhibit 4-7 summarizes the minimum vertical clearances for various roadway classifications and conditions passing under a crossing road or bridge structure.

Exhibit 4-7
Minimum Vertical Clearances

Type Urban and Rural Roadways	Minimum Clearance (ft)
Freeway under Roadway	17.0 (1)
Principal and Minor Arterial under Roadway	17.0 (1)
Collector under Roadway	16.5 (1)
Rural Local under Roadway	14.5 (1)
Roadway under Pedestrian Bridge	Varies (2)
Roadway under Traffic Signal	17.0 (1) (3)
Railroad under Roadway (Typical)	23.29 (4)
Roadway under Sign Truss	17.0 (1)

(1) Value allows 0.50 feet for future resurfacing.
(2) The vertical clearance should be the same as for the roadway under a highway bridge for the designated type of roadway.
(3) Distance is measured from roadway surface to the bottom of the signal at the bottom of the backplate.
(4) Measured from the top of the highest rail. Crossings over switch yards should provide a minimum of 26 feet of vertical clearance.

4.6 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.
2. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 2011.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 5

Cross Section Elements

September 2016

Contents

Chapter 5

Cross Section Elements

The roadway cross section plays a significant role in the basic operational and safety features for the roadway and has a significant impact on the project cost, especially for earthwork. This chapter provides guidance in the design of cross section elements, including the roadway section, shoulders, bicycle lanes, two-way left-turn lanes, on-street parking, curbs, sidewalks, medians, landscape areas, and side slopes. In addition, this chapter provides several typical sections for various roadway types. Refer to the Montana Department of Transportation (MDT) *Geometric Design Standards* document for recommended values for various cross section elements relative to a roadway's functional classification *(1)*. Additional information associated with this chapter can be found in Appendix I.

5.1 DESIGN PRINCIPLES AND APPROACH

A fundamental consideration in establishing cross section elements is an overall vision for the roadway tailored toward the specific users. The intended function of the roadway is a key aspect in the development of an overall vision for its use. For example, the mix of user types on a two-lane, rural highway is often different from the mix of user types on a downtown, urban roadway, thus driving the intended function of these roadways. Because of this, the cross section of these roadways will look very different.

Chapter 1, Section 1.2 provides additional information on applying a performance-based design approach.

With a clear understanding of the mix of user types and intended functions of a roadway, the design team can work toward establishing a cross section that best serves the vision for the roadway. The design team is responsible for understanding whether the cross section elements implemented meet the needs of the different user types and the desired level of performance or function. Different cross section elements have different effects and a different relationship toward one or more aspects of the performance of the roadway. For example, travel lane widths may have an impact on the mobility, safety, and quality of service of a roadway for people driving a motor vehicle but may have limited effect on people walking along the roadway *(2)*.

NCHRP Report 785 **provides additional details on how various design elements may have a direct or indirect effect on various performance measures *(2)*.**

Any cross section elements deviating from the recommended values should also be documented in the Scope of Work Report or the appropriate plans review report.

The MDT *Geometric Design Standards* document provides recommended values for various cross section elements based on the roadway functional classification *(1)*. A design exception is typically required if the recommended values are not met for any cross section elements listed in Chapter 2, Section 2.9.1. Additional information on preparing design exceptions is provided in Chapter 2, Section 2.9. This documentation should include existing cross section information, recommended changes, and justification for design decisions. A performance-based design approach can help document the decision-making process and help the design team understand the trade-offs for evaluating lane widths and other design elements.

For the purposes of the discussion in this chapter, the following terms have been defined, which are also consistent with the definitions in the American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design on Highways and Streets* (Green Book) *(3)*:

1. **Cross section**. A vertical section of the ground and roadway at right angles to the centerline of the roadway, including all elements of a roadway from right-of-way line to right-of-way line.
2. **Roadway**. The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.
3. **Traveled Way**. The portion of the roadway for the movement of vehicles, exclusive of shoulders and bicycle lanes.

Additional cross section elements, and their nomenclature, are illustrated in the following exhibits. The examples are not meant to represent a specific functional classification or land use area. The specific design for each roadway type and land use area may differ depending on the project context.

1. Freeway: see Exhibit 5-1
2. Two-lane roadway with shoulders: see Exhibit 5-2
3. Two-lane roadway with median and curbs: see Exhibit 5-3
4. Two-lane roadway with bicycle lanes and on-street parking:
see Exhibit 5-4

Exhibit 5-1 Example Freeway Cross Section

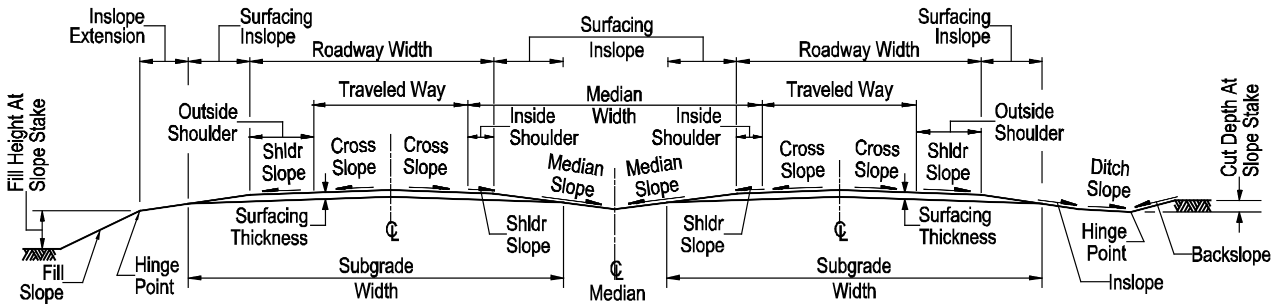


Exhibit 5-2 Example Two-Lane Roadway with Shoulders

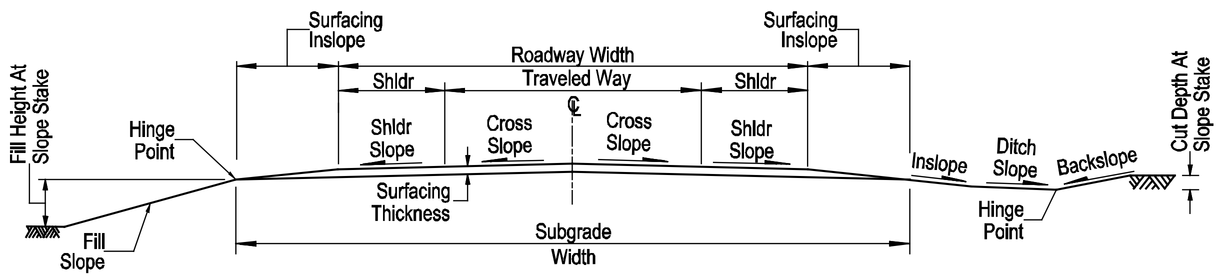


Exhibit 5-3 Example Two-Lane Roadway with Median and Curbs

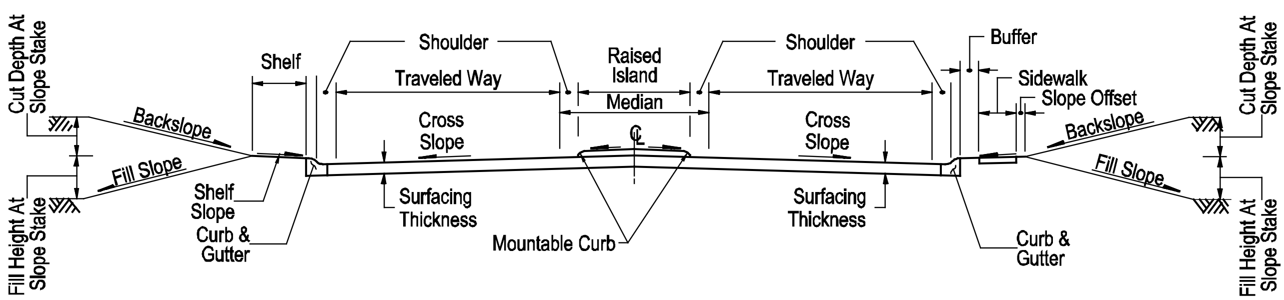
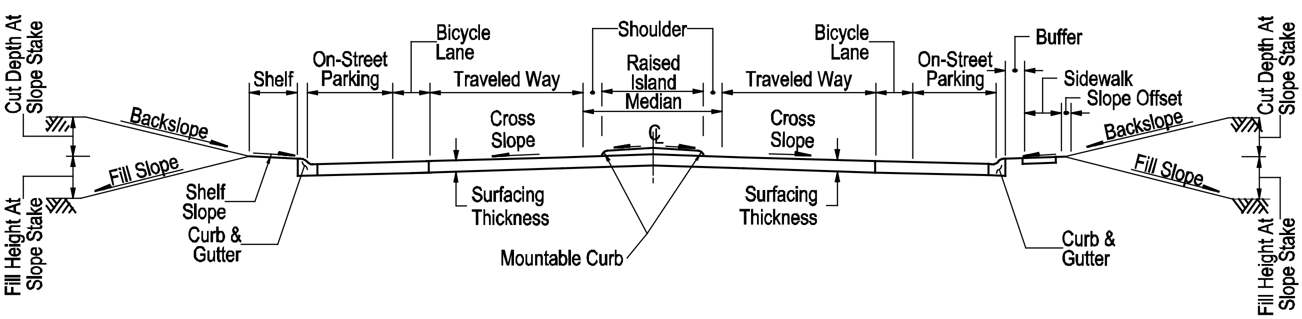


Exhibit 5-4 Example Two-Lane Roadway with Bicycle Lanes and On-Street Parking



5.2 CROSS SECTION ELEMENTS

The most basic roadway section will include two elements: travel lanes and shoulders. Depending on the desired function of the roadway, additional elements can be added to the roadway section. These include additional lanes (such as bicycle lanes, auxiliary lanes, and turn lanes), on-street parking, curbed sections, pedestrian facilities (such as sidewalks and associated buffers), and speed reduction treatments (such as curb extensions and medians). Below is a brief discussion on the roadway width decision process to determine the overall width for a given cross section. The following sections then discuss each individual cross section element and provide guidance for application of each to a given roadway section.

5.2.1 Roadway Width Decision Process

Chapter 2, Section 2.4 provides additional information on the roadway width decision process and the Route Segment Plan.

When making design decisions about roadway cross sections, the design team should consider the *MDT Route Segment Plan*. This plan identifies and defines a consistent pavement width to be used when reconstruction or major widening is conducted on a route segment.

Additional roadway width design information for various types of roadways can be found in the *AASHTO Green Book (3)* and the *FHWA and MDT Guidelines for Nomination and Development of Pavement Projects (5)*. Further coordination with the Traffic and Safety Bureau may also be necessary.

Applying performance-based analysis can help the design team understand the tradeoffs between various roadway widths, while considering the project objectives and contextual environment.

Roadway width decisions can also be examined using a performance-based road design approach. Applying performance-based analysis can help the design team understand the tradeoffs between various roadway widths, while considering the overall project objectives and surrounding contextual environment. Deviations from the design criteria for roadway width may result in the need for a design exception, which can be supported through the documentation process used in a performance-based analysis approach. Chapter 1, Section 1.2 provides additional information on performance-based road design, and Chapter 2, Section 2.9 provides additional information on design exception documentation.

5.2.2 Travel Lanes

Travel lanes are those lanes intended primarily for vehicular use and are designed to provide the appropriate lane width, surface type, and cross slope to serve the desired function and vehicle composition. Lane widths generally vary between 10 feet and 12 feet, depending on traffic volumes, functional classification, and design speed. Refer to the *MDT Geometric Design Standards* document for specific travel lane width standards based on functional classification *(1)*.

5.2.2.1 Surfacing Width

Travel lane width is a key parameter in making effective use of available right-of-way, particularly in constrained environments (established land uses, topography, and natural resources). Travel lane width is typically measured from center of stripe to center of stripe, or from center of stripe to face of curb/edge of pavement (if no striped shoulder).

Many factors influence the decision on appropriate lane width, including roadway location (intersection or segment), functional classification (freeway, arterial, collector, or local road), number of lanes, travel speed, percent of truck or bus traffic, area type (urban or rural), and on-street parking. In turn, lane width can have an effect on the mobility, operations, safety, and accessibility of various users of a roadway. The design team should consider the various types of users for a roadway and understand the trade-offs for making lane width design decisions.

5.2.2.2 Changes in Surfacing Width

When travel lanes are narrowed or widened or the number of travel lanes on a roadway section is reduced, the design team should apply transition taper rates to provide adequate distance for drivers to safely negotiate the width and lateral position changes. For roadways with a design or statutory speed limit of 45 miles per hour or greater, transition tapers are developed such that one foot of width change occurs over a length equal to the design or statutory speed of the roadway. For roadways with a design or statutory speed limit of less than 45 miles per hour, the transition taper rate for one foot of width change is equal to the formula shown in Exhibit 5-5. For design purposes, these values should be rounded up to the next highest multiple of five. Exhibit 5-5 provides transition taper rates for various design speeds.

The design team should coordinate with the Traffic and Safety Bureau for additional guidance on appropriate taper rates for the addition of auxiliary lanes at an intersection.

Exhibit 5-5
Travel Lane Transition Taper Rates

Design Speed (mph)	Transition Taper Rate
20	10:1
25	15:1
30	20:1
35	25:1
40	30:1
45	45:1
50	50:1
55	55:1
60	60:1
65	65:1
70	70:1
75	75:1
80	80:1

For Design Speed (S) < 45 mph, Taper Rate = $(S^2/60):1$
For Design Speed (S) ≥ 45 mph, Taper Rate = S:1
Taper Length (L) = Taper Rate x Offset Distance

5.2.2.3 Surfacing Type

The surfacing type will be dependent on several factors (traffic volume, composition, and soil characteristics) and may also be influenced by the pavement design. The RDM does not address pavement design in detail but relies on the *MDT Pavement Design Manual* for additional details *(6)*. However, the following guidelines can be used when determining if a roadway will be paved or left as gravel.

1. **Rural and Urban Freeways.** All freeways will be paved.
2. **Rural and Urban Minor and Principal Arterials.** All arterials will be paved.
3. **Rural Collectors.** In most cases, rural collectors will be paved. However, existing gravel roads may remain gravel.
4. **Urban Collectors.** Urban collectors will be paved.
5. **Non-State Roadways (including Local Roadways)**. On projects where State and/or Federal funds are used on non-State roadways, the pavement surfacing type will normally be determined at the Preliminary Field Review.

5.2.2.4 Cross Slope

Surface cross slopes are required for proper drainage of travel lanes and are most commonly crowned at the centerline of the roadway section. Roadway sections with depressed medians may be crowned to drain some or all of the pavement area to the depressed median. See Section 5.3.1 for more information on the design and application of depressed medians. The following will generally apply:

1. **Paved**. The travel lane cross slope is typically 2 percent.
2. **Curbed.** On curbed roadways, the cross slope is typically 2 percent. Depending on site conditions, a cross slope between 1.5 percent and 3 percent is acceptable for NHS roadways and between 1 percent and 4 percent is acceptable for non-NHS roadways.
3. **Gravel.** The travel lane cross slope is typically 3 percent. At bridge ends the gravel lane cross slopes must transition to match the bridge cross slopes, which are generally 2 percent.

5.2.3 Shoulders

Shoulders are contiguous with the traveled way and, depending on width, can provide many benefits to a cross section. Generally the wider the shoulder, the greater the benefit provided. Use of shoulders provides:

- Structural support to the traveled way (minimize pavement edge drop-offs);
- Improved operation and increased roadway capacity;
- Improved safety through increased clear recovery area and increased sight distance for horizontal curves;
- Space for emergency and discretionary stops;
- A sense of openness and roadway aesthetics; and
- Space for pedestrian and bicycle use, on-street parking, or both.

The design team should aim to provide a consistent shoulder along a corridor to meet driver expectation, particularly for segments that are narrower than the majority of segments on the corridor.

5.2.3.1 Surfacing Width

Shoulder width will vary according to roadway functional classification, traffic volumes, and urban or rural location. Refer to the *MDT Geometric Design Standards* document for recommended shoulder width values based on functional classification *(1)*. In addition, the design team should consider the following:

1. **Roadside Barriers**. For roadway widths less than 28 feet, shoulder widths should be increased to 2 feet when a roadside barrier is present. Chapter 9 provides more information on offsets to barriers.
2. **Curb and Gutter.** The minimum shoulder width adjacent to a curb is 2 feet measured from the edge of the traveled way to the face of curb.
3. **On-Street Parking.** Shoulders may be eliminated altogether or reduced in width when on-street parking is provided.

Refer to Exhibits 5-21 and 5-22 for typical section illustrations of shoulder width and on-street parking adjacent to curb.

5.2.3.2 Changes to Surfacing Width

In general, the following taper rates should be used for shoulder width transitions:

- For design speeds of 45 mph or greater, use a 25:1 taper rate
- For design speeds less than 45 mph, use an 8:1 taper rate

Adjustments to shoulder transition rates may be appropriate to fit site constraints or reduce the number of typical sections.

5.2.3.3 Surfacing Type and Cross Slope

The type of surfacing and cross slope used for the shoulder should match that used for the traveled way. The cross slope may vary in areas where adjacent development or access requires modification. Examples include meeting drainage needs, limiting roll over differences (approaches to superelevated roadways), and matching to existing features on rehabilitation projects.

5.2.3.4 Subgrade Slopes

The following applies for subgrade slopes:

1. **Tangent Sections**. For tangent sections, the cross slope of the top of the subgrade should be the same as the cross slope of the paved surface.
2. **Superelevated Sections.** For superelevated sections, the cross slope of the top of subgrade should be the same as the cross slope of the paved surface from the subgrade shoulder (hinge point in fill sections) on the high side of the section to a point directly below the edge of the shoulder on the low side of the section. From this point to the subgrade shoulder on the low side, the subgrade cross slope should match the cross slope of the normal crown section (2 percent for paved roadways). This change in subgrade cross slope results in the subgrade shoulder at the inside of the superelevated section being the same distance from the centerline of the

Refer to the typical section exhibits in Section 5.6 for illustrations of subgrade slopes for different roadway types and superelevation conditions.

pavement as the subgrade shoulder of the tangent section. Maintaining a constant location of the subgrade shoulder on the low side of curves maintains the ditch offset distance, reduces depressions in the ditch grade, and aids in the staking of the subgrade.

3. **Variable Surfacing Depths**. Where adjoining typical sections have different surfacing depths, use a taper rate of 20:1 to transition between the subgrade widths.

5.2.4 Dedicated Bicycle Lanes

Chapter 7 provides additional information on dedicated bicycle lane design considerations.

Dedicated bicycle lanes should be considered when evaluating the cross section of a roadway. If a roadway is expected to have a high volume of bicyclists or if the roadway is a designated bicycle route, the cross section should provide adequate space for a dedicated bicycle lane, separate from vehicles and pedestrians. If shoulder rumble strips are present on the roadway, the bicycle lane width should be exclusive of the width of the rumble strips.

Additional information on dedicated bicycle lanes is provided in Chapter 7, and the design team should also reference the *AASHTO Guide for the Development of Bicycle Facilities (7)*. Refer to the *MDT Geometric Design Standards* document for recommended bicycle lane width values based on functional classification *(1)*.

5.2.5 Rumble Strips

Longitudinal shoulder and centerline rumble strips may be added to a roadway cross section to alert drivers who may be tired or inattentive. When adding rumble strips to the roadway cross section, the design team should consider the presence of bicyclists, pavement life, maintenance operations, and initial construction costs. Rumble strips should be installed in accordance with *MDT Rumble Strip Guidance* and in conjunction with the MDT Detailed Drawings (Chapter 14) or project plan details. Additional national guidance for rumble strip design and installation is provided in *NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips (8).*

5.2.6 Auxiliary Lanes

Auxiliary lanes are any lanes beyond the basic through travel lanes occurring along a roadway segment (auxiliary turn lanes and auxiliary through lanes at intersections are discussed in Chapter 6). They are intended for use by vehicular traffic for specific functions, such as truck climbing lanes, passing lanes, and two-way, left-turn lanes. With the exception of two-way, left-turn lanes, the width of an auxiliary lane is typically the same as that of the adjacent through lane. It may be justified to provide a narrower width due to restricted right-of-way. Also, the cross slope of the auxiliary lanes should match that of the adjacent travel lanes.

5.2.6.1 Auxiliary Lanes on Freeways

An auxiliary lane on a freeway is defined as the portion of the roadway adjoining the through lanes for speed change, turning, storage for turning, weaving, truck climbing, and other purposes that supplement through-traffic movement. An auxiliary lane should not trap a driver at its termination point or the point where it continues onto a ramp or turning roadway. The width of the auxiliary lane should be equal to the width of the adjacent through lanes. The width of the shoulder adjacent to the auxiliary lane should be 10 feet unless the roadway is located in mountainous terrain, where 8 feet may be used. Generally, auxiliary lanes should be parallel to the adjacent through lanes. Auxiliary lane lengths should be in accordance with values given in Chapter 10 of the *AASHTO Green Book (3)*.

5.2.6.2 Passing Lanes

In some situations it will be necessary to provide additional lanes to allow vehicles to make passing movements. A passing lane is defined as a short added lane provided in one or both directions of travel on a two-lane, two-way highway to improve passing opportunities. They may present a relatively low-cost improvement for traffic operations by breaking up traffic platoons and reducing delay on roadways with inadequate passing opportunities. Truck-climbing lanes are one type of passing lane used on steep grades to provide passenger cars with an opportunity to pass slow-moving trucks. The Traffic and Safety Bureau will typically determine the need for passing lanes.

Coordinate with the Traffic and Safety Bureau for additional guidance related to passing lanes.

5.2.6.3 Two-Way, Left-Turn Lanes (TWLTL)

Two-way, left-turn lanes (TWLTL) are a cost-effective method to accommodate a continuous left-turn demand and reduce delay and crashes compared to an undivided roadway section. The Traffic and Safety Bureau will typically determine the need for TWLTLs. In general, conditions where a TWLTL should be considered include areas with a high number of approaches per mile, areas with a high-density of commercial development, and areas with a relatively continuous demand for mid-block left turns.

Coordinate with the Traffic and Safety Bureau for additional guidance related to two-way, left-turn lanes.

The desirable width for a TWLTL is 14 feet for all roadway types, urban and rural. For rural areas, the minimum width for a TWLTL is 14 feet. For urban principal arterials, the minimum TWLTL width is 12 feet, and for urban minor arterials and collectors, the minimum TWLTL width is 11 feet. In general, the desirable width should be used for roadways with higher volumes, higher speeds, in industrial areas, or combinations thereof. Refer to the *MDT Geometric Design Standards* document for specific TWLTL width standards based on functional classification *(1)*.

Roadways requiring installation of a TWLTL are often located in areas of restricted right-of-way, and conversion of the existing cross section may be challenging. To obtain the TWLTL width, consider the following options:

- Acquire additional right-of-way to expand the roadway width by the amount needed for the TWLTL,
- Eliminate existing buffer areas behind curbs and reconstructing curb and gutter and existing sidewalks,
- Eliminate existing parking lanes,
- Eliminate or reduce the width of existing shoulders and ditches,
- Reduce the width of existing through lanes, and/or
- Reduce the number of existing through lanes.

Prior to reducing shoulder width, consider the volume of bicycles.

The design team should carefully evaluate the trade-offs between the benefits of the TWLTL and the negative impacts of the alternatives listed above. This may involve a capacity analysis, a study of the current and anticipated use of the corridor, or an evaluation of the existing crash history. This evaluation should be coordinated with the MDT Traffic and Safety Bureau.

At all intersections with public roads, the TWLTL should either be terminated in advance of the intersection to allow for the development of an exclusive left-turn lane, or else the TWLTL should be extended up to the intersection. Where the TWLTL is extended up to the intersection, the pavement markings will switch from two opposing left-turn arrows to one left-turn arrow only where justified by traffic volumes. When determining the intersection treatment, consider the following:

1. **Signalization**. At signalized intersections, the TWLTL should be terminated because these intersections will typically have an exclusive left-turn lane. At unsignalized intersections, the TWLTL may be extended through the intersection if an exclusive left-turn lane is not justified.
2. **Turning Volumes**. The left-turn demand into the intersecting road is a factor in determining the proper intersection treatment. As general guidance, if the minimum storage length will govern, it will probably be preferable to extend the TWLTL up to the intersection and not provide an exclusive left-turn lane.
3. **Length of TWLTL**. The TWLTL should have sufficient length to operate properly. A TWLTL can be interrupted by the need to provide specific left-turn treatments at public intersections and high-volume approaches. This may still allow room to accommodate mid-block access between these left-turn treatments. On two-lane, rural roadways, the overall length needs to be evaluated because a TWLTL may encourage inappropriate passing when carried for extensive distances and will contribute to the overall cost and right-of-way impacts of the roadway.
4. **Operational/Safety Factors**. Extending the TWLTL up to an intersection could result in operational or safety issues. Some drivers may, for example, pass through the intersection in the TWLTL and turn left just beyond the intersection into an approach which is very close to the intersection. If operational or safety issues are known or anticipated at an intersection, it may be preferable to remove the TWLTL prior to the intersection and provide an exclusive left-turn lane.

The design team should coordinate with the Traffic and Safety Bureau on the appropriate treatment and design of TWLTLs and exclusive left-turn lanes at intersections.

5.2.7 On-Street Parking

Coordinate with the Traffic and Safety Bureau for additional guidance related to parking.

The decision to retain existing on-street parking or to introduce on-street parking will typically be made by the Traffic and Safety Bureau and be based on a case-by-case assessment in cooperation with the local community. Adjacent land uses may create a demand for on-street parking along a roadway in an urban area. On-street parking provides convenient access for motorists to businesses and residences but may impact the traffic operations and safety on a corridor. The design team should consider the project context and understand the trade-offs when making design decisions for on-street parking.

The two basic types of on-street parking are parallel and angle parking (includes forward and back-in angle parking). The total entrance and exit time for parallel parking exceeds that required for angle parking. Parallel parking and back-in angle parking require a vehicle to stop in the travel lane and await an opportunity to back into the parking space. However, angle parking requires a greater cross section width. Therefore, when roadway space is limited, parallel parking is the preferred arrangement.

When additional roadway space is available, angle parking provides more spaces per linear foot than parallel parking. When angle parking is considered, back-in angle parking is the preferred arrangement. Both forward and back-in angle parking have similar common dimensions, but the back-in angle parking is superior for safety reasons due to better visibility when leaving. For roadways with high motor vehicle, pedestrian, and bicycle volumes, or where drivers find their views blocked by large vehicles or other objects, back-in angle parking provides greater safety benefits over forward angle parking. Back-in angle parking prevents drivers from backing blindly into an active traffic lane. Also, the open doors of the vehicle block pedestrian access to the travel lane and guide pedestrians to the sidewalk, which is a safety benefit, particularly for children. Furthermore, back-in angle parking positions cargo loading on the curb, rather than in the roadway *(9)*.

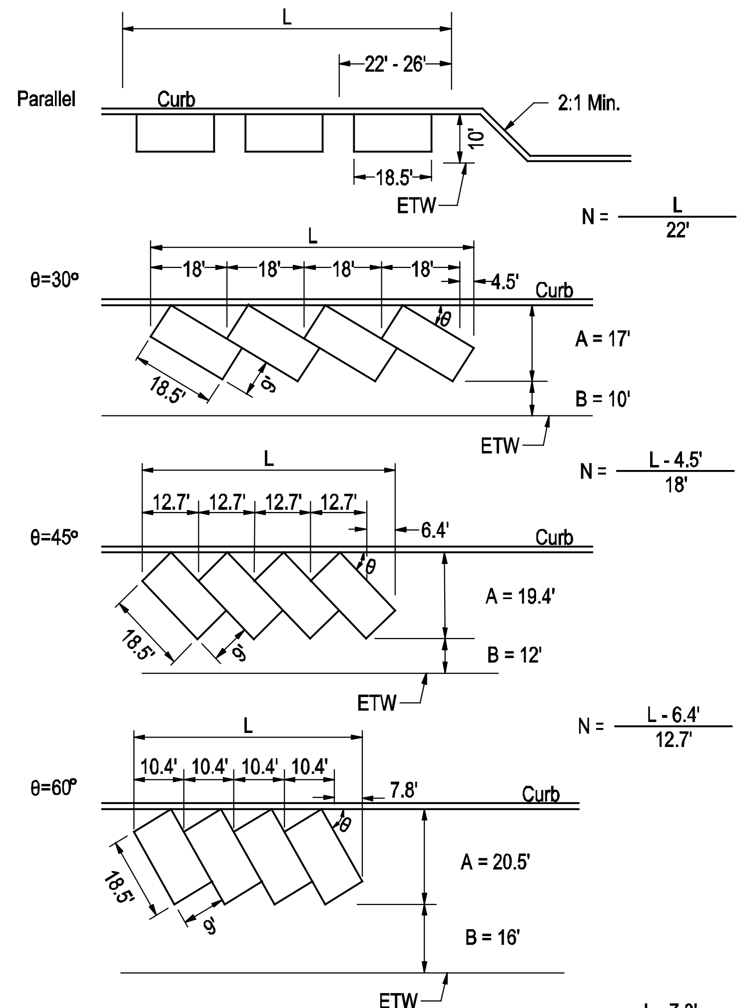
The following summarizes MDT's design criteria for on-street parking:

1. **Stall Width**. The desirable width for parallel parking stalls is 10 feet. For parallel parking, stall widths are measured from the edge of traveled way to the face of curb. The desirable width for angle parking stalls is 9 feet, measured from stripe to stripe. Refer to the *MDT Geometric Design Standards* document for recommended parking stall width values based on functional classification *(1)*.
2. **Stall Layout**. Exhibit 5-6 provides the layout criteria for parking stalls for various configurations. The exhibit also indicates the number of stalls which can be provided for each parking configuration for a given curb length. For angle parking, desirably, the roadway width allocated to parking will be the sum of "A" and "B" as shown in Exhibit 5-6.

   "A" is the desired distance between the face of curb and the back of the stall. "B" is the minimum clear distance needed between the back of the parking stalls and the edge of traveled way to allow for a parked vehicle to pull into or out of the stall and clear adjacent parking vehicles without encroaching on the traveled way. In constrained areas, a portion of the "B" dimension may need to be allocated to the through travel lane, thereby reducing the roadway width allocated to angle parking.

   For dimension "A", it is assumed that the bumper of a parked car does not extend beyond the face of curb. In constrained locations, it can be assumed that the car will move forward until its tire contacts the curb. The design team should provide adequate sidewalk width to meet *Americans with Disabilities Act (ADA)* requirements to accommodate this bumper overhang distance if needed. In these cases, the "A" distances in the figure may be reduced as shown in Exhibit 5-7.

Exhibit 5-6
Curb Parking Configuration



L = Given Curb Length With Parking Spaces
N = Number of Parking Spaces Over Distance, L
A = Required Distance Between Face of Curb and Back of Stall
B = Minimum Clear Distance Needed For a Parked Vehicle To Pull Into or Out of Stall Without Encroaching on Traveled Way
ETW = Edge of Traveled Way

Exhibit 5-7
Parking Stall Additional Reduction in "A"

Angle of Parking	Additional Reduction in "A"
30 degree	1.3 feet
45 degree	2.0 feet
60 degree	2.3 feet

3. **Cross Slope**. The cross slope of the parking lane should match that of the adjacent through travel lane whenever possible. However, cross slopes

between 1 percent and 4 percent are allowed to fit actual field conditions. The longitudinal slope of the parking lane should be equal to or steeper than the adjacent through lane to promote proper drainage.

4. **Accessibility for Disabled Individuals**. Where on-street parking is permitted, a certain number of parking spaces should be provided for accessibility for the disabled, and their design should meet the applicable accessibility design criteria.
5. **Intersection Curb Radii.** Parking may need to be restricted for a certain distance from intersections to allow the design vehicle to properly negotiate turning movements at the intersection. Chapter 6 provides additional information on intersection design considerations.
6. **Location.** For most sites, a sight distance evaluation should be conducted when locating parking spaces. In addition to State and local regulations, these guidelines should be followed when locating parking spaces:
   a. Locate at least 20 feet from any crosswalk.
   b. Locate at least 10 feet from the beginning of the curb radius at mid-block approaches.
   c. Locate at least 50 feet from the nearest rail of a railroad/highway crossing.
   d. Locate at least 30 feet from the approach leg of any intersection with a flashing beacon, stop sign, or traffic signal.
   e. Locate parking away from areas designated by local traffic and enforcement regulations (e.g., near school zones, fire hydrants). See local ordinances for additional information on parking restrictions.
   f. Locate parking away from bus stops.
   g. Parking should not be located on bridges or within a highway tunnel.
   h. Parking should not be located across from a T- intersection.

5.2.8 Curbs and Curbed Sections

Curbs are often used on urban roadways to facilitate proper drainage, delineate the pavement edge, channelize vehicular movements, control access, limit right-of-way needs, provide separation between vehicles and pedestrians, and improve aesthetics. Curbs are typically not used in rural areas. For urban and transitional areas, selecting a curbed section or uncurbed section depends upon many variables, and the decision will be made on a case-by-case basis. Evaluate the following factors to determine whether or not a curbed section is preferred:

- Existing conditions (curbed or uncurbed);
- Local preference;
- Drainage impacts;
- Construction costs;
- Impacts on maintenance operations;
- Roadside safety impacts (see Chapter 9);

- Sidewalk guidelines (see Section 5.2.9 and Chapter 7, Section 7.3.3.2);
- Control of access to abutting properties;
- Impacts on traffic operations, for example, vehicular channelization at intersections;
- Right-of-way restrictions; and
- Vehicular speeds (the use of curbs is not preferred where speeds are greater than 45 miles per hour).

Where a curbed section is warranted, MDT uses concrete curb exclusively. Typically, the curb will be a mountable sloped shape. This applies to both outside curbs and curbs used for raised medians. On roadways with curbs and no sidewalks, a shelf (a flat area typically 3 feet in width, measured from the back of curb) is provided, and the side slope is located beyond the shelf. See the typical sections in Section 5.6.

Curbs must be designed with curb ramps at all pedestrian crosswalks to provide adequate access for the safe and convenient movement of physically disabled individuals. The MDT Detailed Drawings provide specifics for those curbs used by MDT.

5.2.9 Pedestrian Facilities

Refer to Chapter 7 for information on determining the need for pedestrian facilities and for guidance in selecting the proper type of facility.

Cross section design considerations for pedestrian facilities include sidewalks (both attached and detached) and pedestrian and shared use paths. The following sections provide design guidelines for each facility type.

5.2.9.1 Sidewalks

If a sidewalk is justified based on the guidance provided in Chapter 7, Section 7.3.3.2, the design team should consider the following:

1. **Typical Widths**. Sidewalks should typically be 6 feet wide or wider depending on the project context. The minimum sidewalk width is 5 feet, as measured from the back of the curb. Sidewalk widths vary depending on specific characteristics along the roadway including land use, obstructions, and/or appurtenances along the roadway. Also, the design team should consider compatibility with local city and community criteria during design.
2. **Appurtenances**. The design team should consider the impacts of roadside appurtenances within the sidewalk (e.g., fire hydrants, parking meters, utility poles, signs). These elements will reduce the effective width of the sidewalk because they interfere with the pedestrian’s natural walking path. Preferably, place these appurtenances behind the sidewalk, or within the furniture zone. If they are placed within the sidewalk, the sidewalk should have a minimum clear width of 4 feet around the appurtenance; preferably 5 feet of clear width should be provided. The clear width will be measured from the edge of the appurtenance to the edge of the sidewalk.
3. **Central Business District (CBD) Areas**. The entire area between the curb and any adjacent buildings is often fully used as a paved

sidewalk. Coordinate with local agencies for potential encroachments under sidewalks.

4. **Cross Slope.** The maximum cross slope on the sidewalk is 2 percent. Typical practice is to design sidewalks at a cross slope of 1.5 percent to allow for potential deviations and flexibility during construction. Sidewalks should be sloped toward the roadway unless site constraints dictate otherwise in order to convey drainage runoff into the roadway and away from private properties.
5. **Buffer Areas.** If the available right-of-way is sufficient, buffer areas between the curb and sidewalk are desirable. Refer to Section 5.2.10 for additional information on buffer areas.
6. **Sidewalk Material.** Sidewalks will be concrete.
7. **Bridges.** The Bridge Bureau is responsible for the dimensioning and structural design of all sidewalks on bridges.

If a sidewalk is placed on a bridge, it may be necessary to provide the standard bridge rail to separate the vehicular traffic from pedestrians and then use a pedestrian rail on the outside edge of the sidewalk. Consider the need for a separate pedestrian rail on a case-by-case basis. Evaluate the following factors:

- Design speed;
- Pedestrian volumes;
- Traffic volumes;
- Crash history;
- Geometric impacts (e.g., sight distance);
- Practicality of providing proper end treatments;
- Construction costs; and
- Local preference.

If a bridge with a sidewalk is on a designated bicycle route or experiences heavy bicycle traffic, and a dedicated bicycle lane is not provided, the railings/barriers must be a minimum of 4.5 feet high. In addition, barriers should have smooth rub rails at a 3.5-foot height. The Bridge Bureau will be responsible for the final decision on when to use a pedestrian rail in combination with the standard bridge rail. Due to the steepness of the roadway inslopes near the bridge ends, it is recommended that the pedestrian rail extend at least 25 feet beyond the end of the bridge.

The need to extend the rail and the length of the extension should be determined at the Plan-in-Hand.

5.2.9.2 Pedestrian & Shared Use Paths

Pedestrian and shared use paths are typically constructed adjacent to roadways without curb and gutter, with a buffer area between the roadway and pathway. Pedestrian and shared use paths may be constructed in conjunction with a curb and gutter roadway section where the pathway is established for recreational use and is designed as part of the overall landscaping. The following will apply to the design of pedestrian and shared use paths:

Refer to Chapter 7 for additional information on pedestrian and shared use paths.

1. **Typical Width.** The minimum paved width for a pedestrian path is 6 feet, with 8 feet being the preferred width. A minimum 10-foot width is recommended if the path will be a shared use path with bicycles. According to the *AASHTO Guide for the Development of Bicycle Facilities*, a

reduced width of 8 feet may be used for shared use paths in very rare circumstances *(7)*.

2. **Appurtenances**. Do not place appurtenances within a pedestrian or shared use path.
3. **Cross Slope.** The maximum cross slope on a pedestrian or shared use path is 2 percent. Typical practice is to design pathways at a cross slope of 1.5 percent to allow for potential deviations and flexibility during construction. Generally, slope the pathway toward the roadway; however, it may be sloped in either direction as determined by field conditions. For shared use paths, the recommended cross slope is 1 percent according to the *AASHTO Guide for the Development of Bicycle Facilities (7).*
4. **Separation.** The separation between the roadway and the pedestrian path should be as wide as practical, but at least a minimum of 3 feet. For shared use paths, a 5-foot minimum separation is recommended according to the *AASHTO Guide for the Development of Bicycle Facilities (7).*
5. **Pathway Material**. Pedestrian and shared use paths will typically be paved with bituminous asphalt.
6. **Bridges**. The pedestrian or shared use path should connect to the bridge, unless a separate, adjacent pathway bridge is provided. The Bridge Bureau is responsible for designing the bridge to accommodate the pathway across the bridge.

5.2.10 Buffer Areas

The buffer area is the area between the roadway and the sidewalk that provides space between motorized vehicle traffic and non-motorized users (pedestrians and bicycles). Buffer areas may be included as part of the cross section, particularly in urban and transitional areas, to enhance public safety by separating various users and provide an aesthetic feature to the community. Buffer areas should be at least 3 feet wide to be effective and, if practical, should be wider. Landscaping may also be installed within a buffer area, median, or splitter island. Additionally, planting vegetation may be installed for erosion-control purposes. If the area is landscaped, additional width is often necessary to accommodate plantings.

Landscape designs in a buffer area or median should consider the following:

- Provide sufficiently wide, clear, and safe pedestrian pathways and bicycle facilities within existing or planned right-of-way.
- Install and maintain shrubs and trees to meet sight distance and roadside clearance guidelines.
- Evaluate street light poles for their proximity to trees to maintain the appropriate roadway lighting, as well as lighting the sidewalk.
- Design proper drainage for landscaping that requires irrigation. Chapter 11 provides additional design information for drainage and irrigation designs.
- Ongoing maintenance of irrigation, shrubs, trees, and other landscape features should be considered in the design.

Landscaping can also provide erosion control and should be developed to keep with the character of the roadway and its environment. The design team should consider preserving or transplanting any existing vegetation where practical. The design should help improve the aesthetics without increasing the potential crash severity associated with errant motor vehicles.

5.3 MEDIANS

A median is defined as the portion of a divided highway separating directionally opposed traveled ways. Depending on the type of median, the principal functions of a median are to:

- Provide separation from opposing traffic;
- Prevent undesirable turning movements;
- Provide an area for deceleration and storage of left-turning vehicles;
- Provide an area for storage of vehicles for emergency stopping;
- Facilitate drainage collection;
- Provide a recovery area for run-off-the-road vehicles;
- Provide an opportunity for two-stage crossing and turning movements;
- Improve sight lines for left-turning vehicles relative to oncoming traffic;
- Provide an area for pedestrian refuge; and
- Provide width for future lanes.

Coordinate with the Traffic and Safety Bureau to determine the appropriate placement of medians.

5.3.1 Median Types

Medians may be depressed, raised, or flush with the roadway surface and should be highly visible both day and night. The three types of medians, and their typical application, are discussed below. Section 5.6 provides typical sections for various median types.

5.3.1.1 Depressed Medians

A depressed median is typically used on freeways and other divided rural arterials. Depressed medians should have good drainage characteristics. Depressed medians should be as wide as practical to allow for the addition of future travel lanes on the inside while maintaining a sufficient future median width.

The minimum width for depressed medians is 36 feet. Depressed medians 36 feet to 44 feet wide should be developed with 6:1 side slopes to the point where the side slopes meet. This allows for a ditch with sufficient depth to accommodate the drainage runoff. Depressed medians greater than 44 feet wide to 76 feet wide should be developed with 6:1 side slopes out to a minimum of 15 feet and a maximum of 24 feet from the median edge of pavement depending on the subgrade and intermediate surfacing widths. When the width of the median is greater than 76 feet, the two roadways of the divided facility are treated as independent roadways. In these cases, a 6:1 side slope should be developed on either side of the depressed median for 10 feet from the daylight of the subgrade to the hinge point. From this point, variable side slopes may be used to best fit the terrain and drainage needs. See Exhibits 5-9 through 5-14 at the end of this chapter for illustrations of the various depressed median conditions described above.

5.3.1.2 Raised Medians

Raised medians may be used on roadways in urban and transitional areas to control access and left turns. The use of raised medians is not recommended on high-speed roadways (speeds greater than 45 miles per hour). Raised medians should be illuminated such that they are visible under nighttime conditions. See Section 5.3.3 for information on the design of raised medians.

5.3.1.3 Flush Medians

Flush medians are often used on urban roadways. The typical width of a flush median should range from 4 feet to 16 feet. They are paved and striped for lane delineation. The design team should coordinate with the Traffic and Safety Bureau to determine if flush medians are appropriate for traffic volumes present on the roadway. To provide proper drainage, flush medians are typically crowned in the center with a cross slope equal to the cross slope of the adjacent travel lanes.

One potential disadvantage of flush medians is that they do not effectively deter cross-median vehicular movements, nor do they provide refuge for pedestrians. If this is perceived as a problem, the design team, in coordination with the Traffic and Safety Bureau, should consider providing a raised median.

Two-way, left-turn lanes (TWLTL) are also considered flush medians. Desirably, the roadway cross section with a flush median will allow ultimate development for a future TWLTL in urban and transitional areas. See Section 5.2.6.3 for more information and design details for TWLTLs.

5.3.2 Selecting a Median Type

Each median type provides unique advantages and disadvantages. The design team should evaluate the impacts of each median type on a case-by-case basis and coordinate the selection of a median type with the Traffic and Safety Bureau. The comments below may be used to guide the decision-making process.

When compared to flush medians, raised medians offer several advantages, including the following:

- Mid-block left turns are controlled;
- Left-turn channelization can be more effectively delineated;
- A distinct location is available for traffic signs, signals and pedestrian refuge;
- Limited physical separation is available;
- Uncontrolled cross-traffic movements are prevented; and
- They reduce the potential for head-on collisions.

The disadvantages of raised medians when compared to flush medians include the following:

- Access for emergency vehicles may be more difficult;

- Prohibiting mid-block left turns may overload intersections and may increase the number of U-turns, and they also may impact other roadways in the vicinity of the corridor;
- They may need greater roadway widths to serve the same function (for example, left-turn lanes at intersections) because of the raised island and offset between curb and travel lane;
- Curbs may result in adverse vehicular behavior upon impact;
- They may cause drainage and snow removal issues;
- They are more expensive to construct and more difficult to maintain; and
- Prohibiting mid-block left-turns causes drivers to take inconvenient alternative access routes to and from adjacent properties.

5.3.3 Raised Median Design

If a raised median will be used, consider the following in the design of the median:

Refer to Chapter 6 for information and guidance on the location and design of openings in raised medians.

1. **Curb Type**. Typically, mountable concrete curbs are used for raised medians.
2. **Width.** The width of a raised median is measured from the two inside edges of the traveled ways and includes the median shoulders. For example, a median width of 20 feet provides for:
   a. A 2-foot offset from the through lane shoulder stripe to the face of curb on each side of the raised median, and
   b. A 16-foot raised median from face of curb to face of curb.

   The 16-foot width of the median should allow for the development of a 12-foot wide channelized left-turn lane. Where the raised median exceeds 16 feet, the design team should center the opposing lanes opposite each other at intersections or, if practical, provide left offset left-turn lanes. This will enhance the ability of a left-turning vehicle to see around the opposing left-turning vehicle. Refer to the *MDT Geometric Design Standards* document for recommended median width values based on functional classification *(1)*.
3. **Surfacing.** The raised portion of the median is usually paved with concrete. Alternate treatments such as landscaping should be determined on a case-by-case basis and in collaboration with the local community.
4. **Lighting and Delineation.** Where raised medians are used, the roadway should be well lit, and the medians should be delineated.

Evaluate all existing raised medians within the project limits for their current appropriateness. The existing configuration of the raised median should be evaluated with its consistency to the existing geometric needs. This includes sight distance for the left-turn bays, storage lengths, and turning paths for vehicles entering and exiting the roadway.

5.4 SIDE SLOPES

Refer to Chapter 9 and the *MDT Geometric Design Standards* document for detailed information and recommended ratios for side slopes.

Side slopes on roadway sections refers to both fill slopes and cut slopes used to conform to existing conditions along the roadside. MDT protocol for slope notation is "X:1", where "X" is the horizontal dimension and the vertical dimension is represented by the value of "1". Section 5.6 presents typical sections for side slopes for various types of roadways. The following provides a general discussion of side slopes.

5.4.1 Fill Slopes

Fill slopes are the slopes extending outward and downward from the hinge point to intersect the natural ground line. The fill slope design criteria depend upon the functional classification, fill height, urban/rural location, and the presence of curbs. The design team should also consider right-of-way restrictions, utility considerations, roadside safety, and roadside development in determining the appropriate fill slope for the site conditions. Refer to the MDT *Geometric Design Standards* document for recommended fill slope ratios based on functional classification (*1*).

5.4.2 Cut Slopes

Cut slopes, also called backslopes, are the slopes extending outward and upward from the ditch line to intersect the natural ground line. Refer to the MDT *Geometric Design Standards* document for recommended cut slope ratios based on functional classification (*1*). In earth cuts on roadways without curbs, roadside ditches are provided to control drainage. The ditch section includes the inslope, ditch width, and backslope, as appropriate for the roadway type.

5.4.2.1 Earth Cuts

In earth cuts on roadways without curbs, roadside ditches are provided to control drainage. The ditch section includes the inslope, ditch width, and backslope, as appropriate for the roadway type.

The following will apply to earth cuts:

1. **Snow Drifting**. One of the following two methods can be used to control snow drifting in cuts.
    a. Design the backslope so that an imaginary line between the finished shoulder and the top of the cut (intersection with natural ground) has a slope of 11:1 or flatter.
    b. Increase the width of the flat-bottomed ditch to provide additional snow storage. Use the method described in the Strategic Highway Research Program's *Design Guidelines for the Control of Blowing and Drifting Snow* to determine the necessary width of the ditch *(10)*.
2. **Superelevated Sections.** On superelevated sections, a 6:1 side slope on the high side of the section extends outward and downward from the subgrade shoulder. This slope should extend a sufficient distance such that the distance from the centerline of the pavement (or traveled way

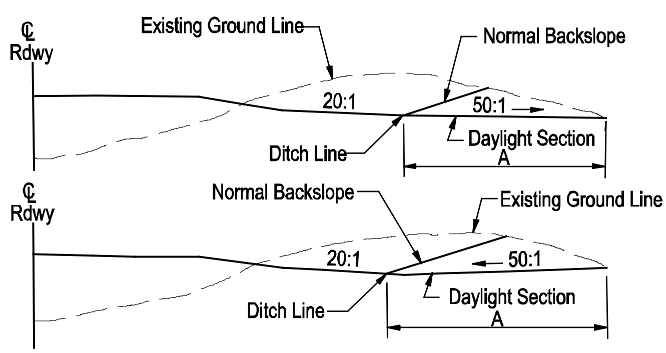
for sections with depressed medians) to the end of the 6:1 side slope is the same as the distance from the centerline of the pavement to the subgrade shoulder on the tangent section. As with the break in the subgrade cross slope, the use of the extended 6:1 slope maintains the ditch offset distance and avoids depressions in ditch grades.

3. **Daylighting.** Daylighting slopes can provide several benefits, including:
    - Enhancing roadside safety;
    - Providing needed fill material;
    - Removing undesirable features;
    - Obliterating existing roadbeds;
    - Providing convenient outfall points for roadside drainage; and
    - Enhancing aesthetics.

    Exhibit 5-8 illustrates how to daylight slopes. A 50:1 slope is typically used either away from or towards the ditch line, as appropriate. The dimension "A" in the exhibit refers to the lateral distance needed to excavate to daylight a slope. Whether a given site should be daylighted, based on "A", will be determined on a case-by-case basis.

Note that daylighting should not be used if it results in the need for a traffic barrier.

Exhibit 5-8
Daylighting



4. **Additional Right-of-Way.** If additional right-of-way is needed to accommodate utilities or to address slope stability, these features will need to be included in the final construction limits or coordinated with the Right of Way Bureau.
5. **Geotechnical Investigations**. Backslopes steeper than 3:1 should be reviewed for stability by the Geotechnical Section.

5.4.3 Existing Roadside Development

Where roadside development is extensive and the general elevation on one side is higher than on the other, an asymmetrical roadway section may be advantageous. Roadway cross slopes less than or greater than the typical cross slopes may be necessary in order to adapt to roadside elevations and constraints. Also, it may be advantageous to offset the crown point from the centerline. Typical locations for offset crown points are at lane lines. Introducing changes in cross slope (additional "crown points") from one lane to another or between the outside travel lane and shoulder is an additional technique for conforming to existing roadside development.

Asymmetrical features should be clearly defined in the typical sections and shown in the cross sections. It will likely also be necessary to provide separate profiles at the top of curbs to match existing development. Providing an asymmetrical cross section may be preferred and more cost effective than reshaping existing sidewalks, parking lots, lawns, or other features to meet the revised profile.

5.5 BRIDGE AND UNDERPASS CROSS SECTIONS

The roadway cross section should be carried across and under bridges, which often requires special considerations because of the confining nature of bridges and their high unit costs.

5.5.1 Bridges

Coordinate with the Bridge Bureau to determine widths on new and reconstructed bridges and on existing bridges to remain in place.

5.5.2 Underpasses

Coordinate with the Traffic and Safety Bureau to determine if future widening of a roadway is anticipated.

The approaching roadway cross section, including shoulders, bicycle lanes, and auxiliary lanes, should be carried through the underpass. Sidewalks may also be necessary through the underpass as described in Section 5.2.9.

When determining the cross section width of an underpass, the design team should also consider the likelihood of future roadway widening. Widening an existing underpass in the future can be extremely expensive and challenging. If the potential for future traffic growth and roadway expansion exists, the design team should evaluate the possibility of providing additional width for the underpass. If appropriate, a reasonable allowance for future widening may be to provide sufficient lateral clearance for one additional lane in each direction.

5.5.3 Traveled Way Width Reductions

When an approaching roadway has a different width than a bridge or underpass, in certain situations the traveled way width may need to be widened or reduced in advance to allow the roadway to pass over or under a bridge. These traveled way width transitions should be designed according to the guidance in Section 5.2.2.2 and using the taper rates in Exhibit 5-5.

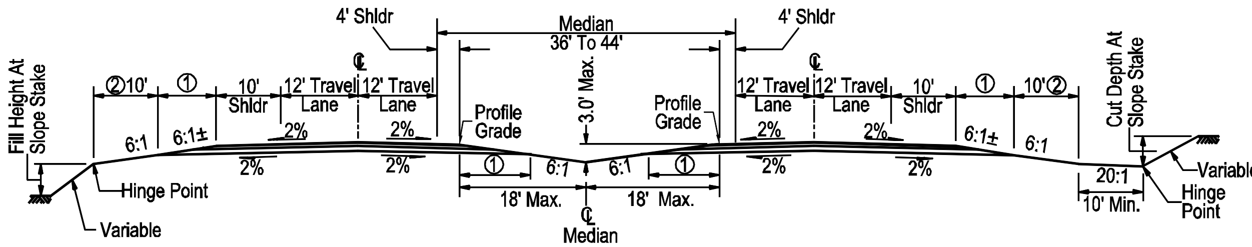
5.6 TYPICAL SECTIONS

The following exhibits present typical sections which will apply to various types of roadways for all projects. The MDT *Geometric Design Standards* presents recommended values for cross section elements based on the roadway functional classification *(1)*. The typical section exhibits are:

1. Exhibit 5-9: Typical Freeway with Depressed Median Section (Tangent Section) (Medians 36 feet to 44 feet);

2. Exhibit 5-10: Typical Freeway with Depressed Median Section (Superelevated Section) (Medians 36 feet to 44 feet);
3. Exhibit 5-11: Typical Freeway with Depressed Median Section (Tangent Section) (Medians >44 feet to 76 feet);
4. Exhibit 5-12: Typical Freeway with Depressed Median Section (Superelevated Section) (Medians >44 feet to 76 feet);
5. Exhibit 5-13: Typical Freeway with Depressed Median Section (Tangent Section) (Medians >76 feet wide);
6. Exhibit 5-14: Typical Freeway with Depressed Median Section (Superelevated Section) (Medians >76 feet wide);
7. Exhibit 5-15: Typical Four-Lane Divided Roadway with Flush Median Section (Tangent Section);
8. Exhibit 5-16: Typical Four-Lane Divided Roadway with Flush Median Section (Superelevated Section);
9. Exhibit 5-17: Typical Four-Lane Divided Roadway with Raised Median Section (Tangent Section);
10. Exhibit 5-18: Typical Four-Lane Divided Roadway with Raised Median Section (Superelevated Section);
11. Exhibit 5-19: Typical Two-Lane Roadway (Tangent Section);
12. Exhibit 5-20: Typical Two-Lane Roadway (Superelevated Section);
13. Exhibit 5-21: Typical Curbed Roadway (Tangent Section);
14. Exhibit 5-22: Typical Curbed Roadway (Superelevated Section);
15. Exhibit 5-23: Typical Off-System Roadway (Tangent Section); and
16. Exhibit 5-24: Typical Off-System Roadway (Superelevated Section)

Exhibit 5-9 Typical Freeway with Depressed Median Section (Tangent Section)
(Medians 36 feet to 44 feet)

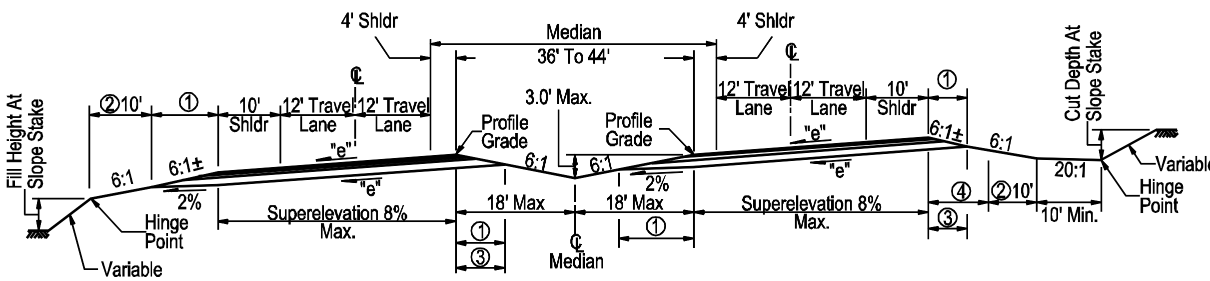


General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

Exhibit 5-10 Typical Freeway with Depressed Median Section (Superelevated Section)
(Medians 36 feet to 44 feet)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

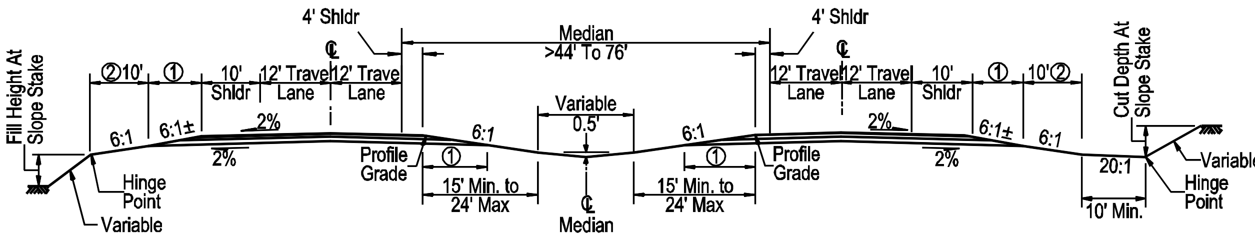
① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

③ Compute distance for each superelevation on the project.

④ This distance will be equal to the ① distance on the tangent section (Exhibit 5-9).

Exhibit 5-11 Typical Freeway with Depressed Median Section (Tangent Section)
(Medians >44 feet to 76 feet)

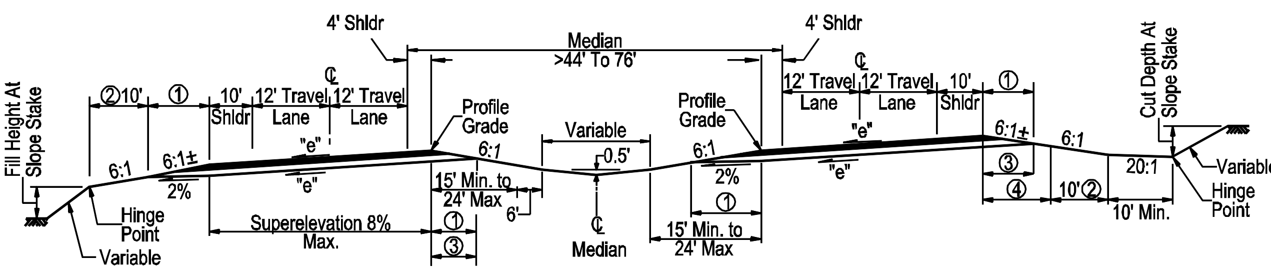


General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

Exhibit 5-12 Typical Freeway with Depressed Median Section (Superelevated Section)
(Medians >44 feet to 76 feet)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

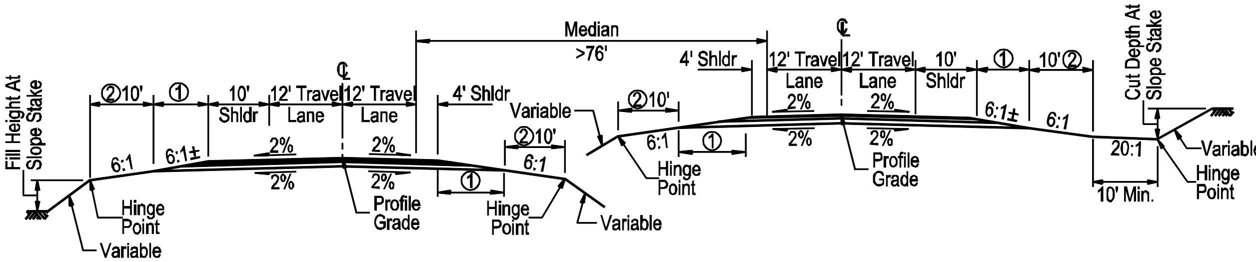
① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

③ Compute distance for each superelevation on the project.

④ This distance will be equal to the ① distance on the tangent section (Exhibit 5-11).

**Exhibit 5-13 Typical Freeway with Depressed Median Section (Tangent Section)
(Medians >76 feet wide)**



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

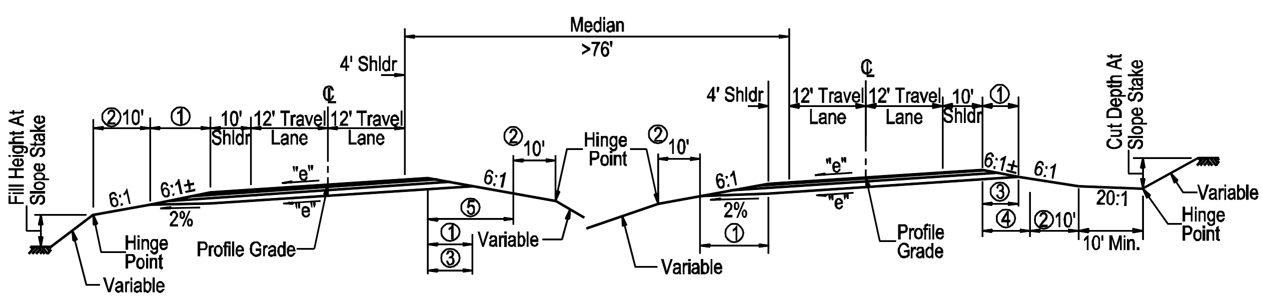
Generally, this typical section will be used only where terrain warrants the use of independent grade lines. Median slope intersections will be determined by the designer to meet individual conditions. In cases where median widths vary (from 36' to 76' and over) within a given project, the profile grade will be carried on the finished median shoulder.

Where practical, natural growth in place between roadways should be preserved.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

**Exhibit 5-14 Typical Freeway with Depressed Median Section (Superelevated Section)
(Medians >76 feet wide)**



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

Generally, this typical section will be used only where terrain warrants the use of independent grade lines. Median slope intersections will be determined by the designer to meet individual conditions. In cases where median widths vary (from 36' to 76' and over) within a given project, the profile grade will be carried on the finished median shoulder.

Where practical, natural growth in place between roadways should be preserved.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

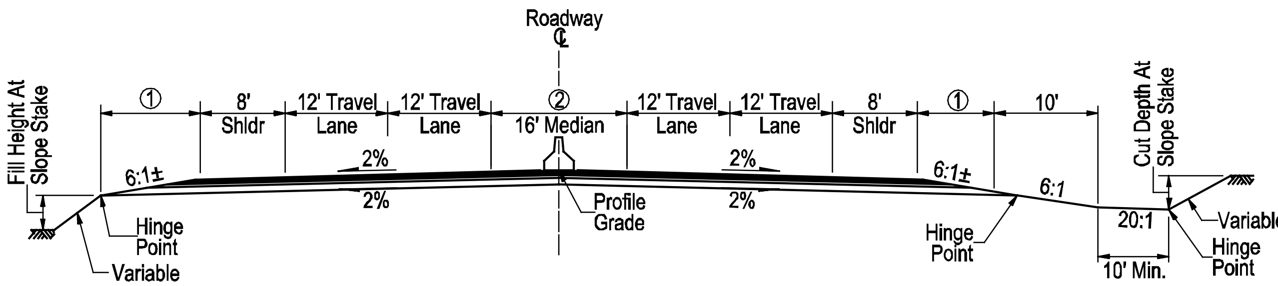
② For rehabilitation projects, an existing 6 foot width may be retained with documentation.

③ Compute distance for each superelevation on the project.

④ This distance will be equal to the ① distance on the tangent section (Exhibit 5-13).

⑤ This distance will be equal to the ① distance on the tangent section plus 10'.

Exhibit 5-15 Typical Four-Lane Divided Roadway with Flush Median Section (Tangent Section)



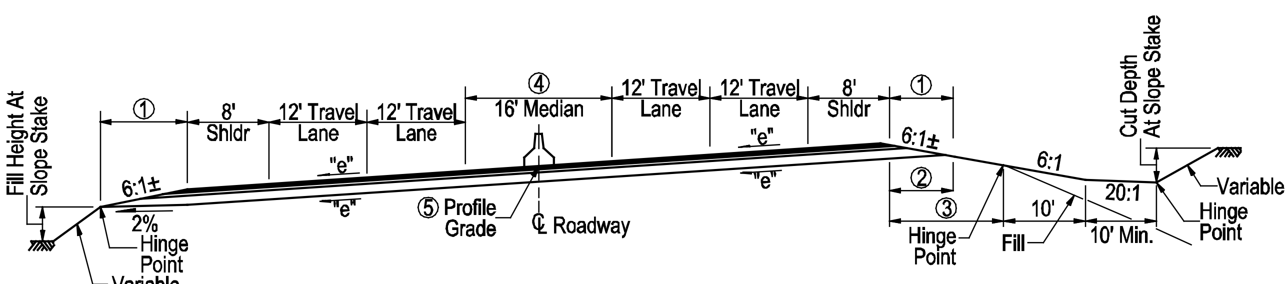
General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

The need for a median barrier will be determined on a case-by-case basis.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② A reduced median width may be used, see MDT Geometric Design Standards

Exhibit 5-16 Typical Four-Lane Divided Roadway with Flush Median Section (Superelevated Section)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

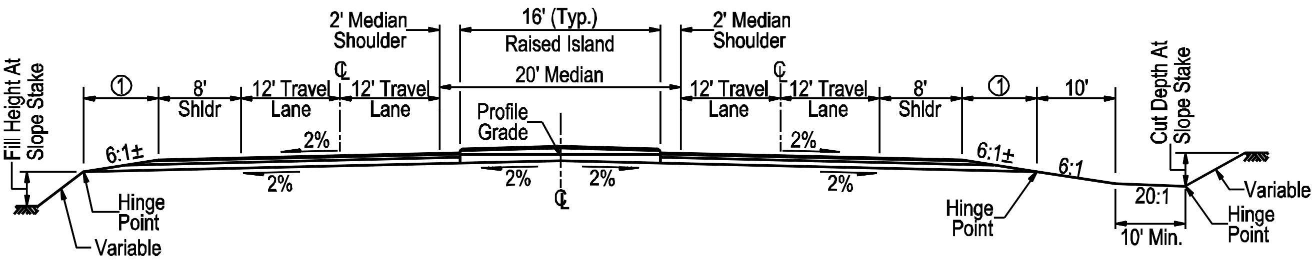
② Compute distance for each superelevation on the project.

③ This distance will be equal to the ① distance on the tangent section (Exhibit 5-15).

④ A reduced median width may be used, See MDT Geometric Design Standards

⑤ For medians >10 feet wide, separate profile grade lines at the median-edge of pavement may be appropriate.

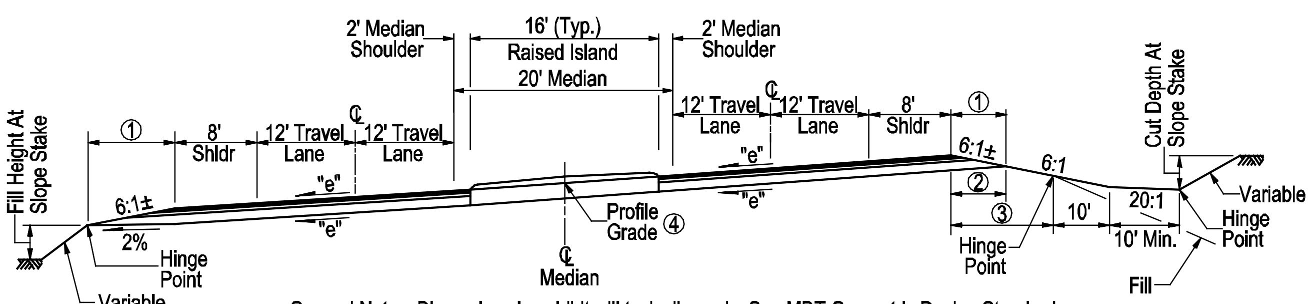
Exhibit 5-17 Typical Four-Lane Divided Roadway with Raised Median Section (Tangent Section)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

Exhibit 5-18 Typical Four-Lane Divided Roadway with Raised Median Section (Superelevated Section)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

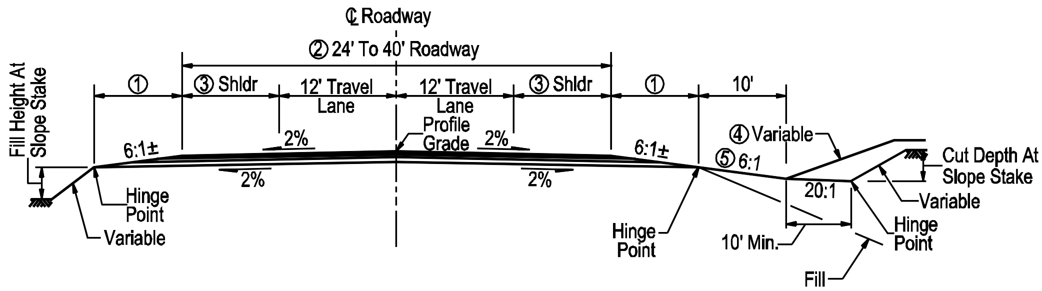
① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② Compute distance for each superelevation on the project.

③ This distance will be equal to the ① distance on the tangent section (Exhibit 5-17).

④ For medians >10 feet wide, separate profile grade lines at the median-edge of pavement may be appropriate.

Exhibit 5-19 Typical Two Lane Roadway (Tangent Section)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

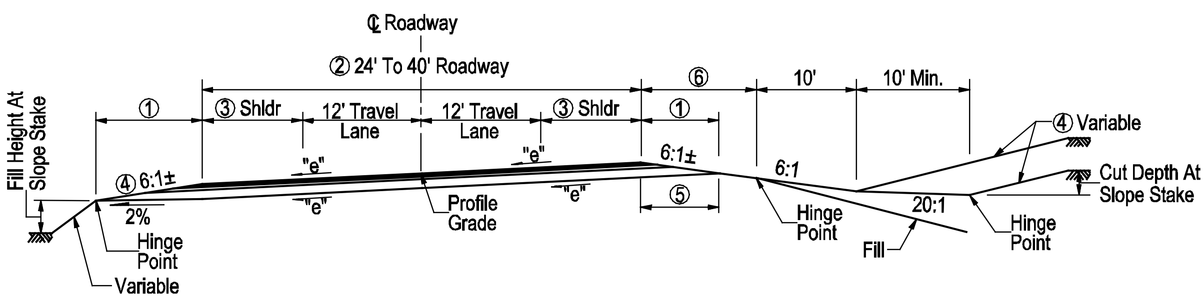
② Roadway width will vary. See MDT Geometric Design Standards for specific criteria.

③ Shoulder width will vary. See MDT Geometric Design Standards for specific criteria. New projects should include full-depth shoulders.

④ V-ditches may be used in special cases. Check Chapter 9: Roadside Safety for traversability criteria for roadside ditches.

⑤ The inslope may be 4:1 for some major collectors, See MDT Geometric Design Standards for specific criteria.

Exhibit 5-20 Typical Two-Lane Roadway (Superelevated Section)



General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② Roadway width will vary. See MDT Geometric Design Standards for specific criteria.

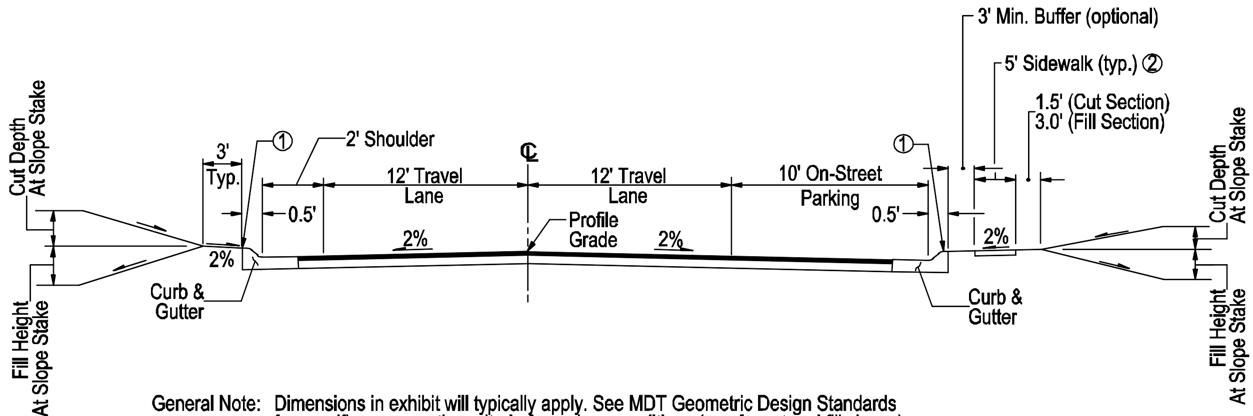
③ Shoulder width will vary. See MDT Geometric Design Standards for specific criteria. New projects should include full-depth shoulders.

④ See Chapter 13: Quantity Summary for method of computing intermediate thickness on low side of curves.

⑤ Compute distance for each superelevation on the project.

⑥ This distance will be equal to the ① distance on the tangent section (Exhibit 5-19)

Exhibit 5-21 Typical Curbed Roadway (Tangent Section)

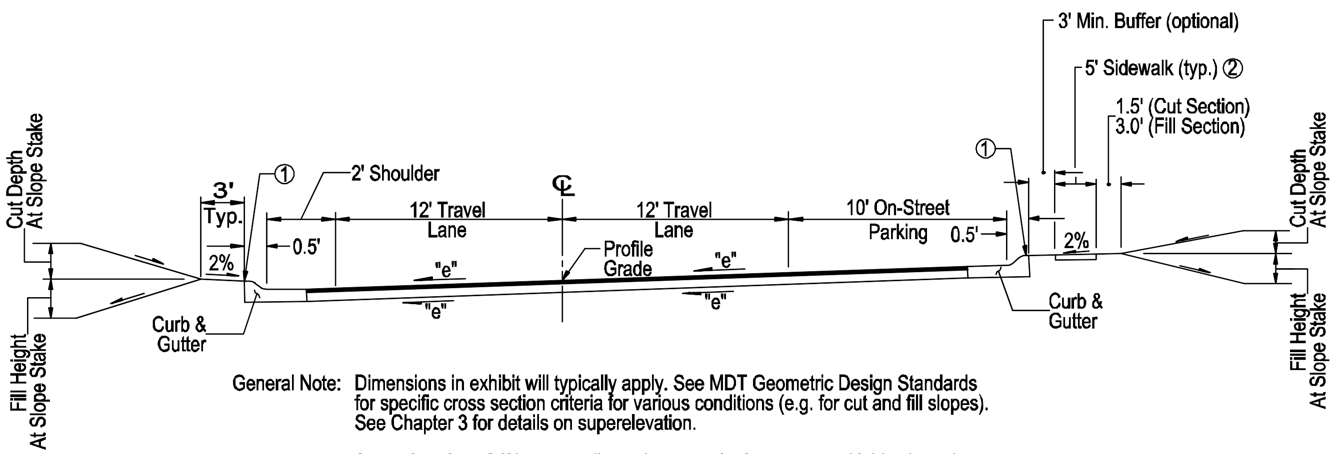


General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes)

① It may be necessary to use separate profiles at the top back of curb to promote positive drainage and to match existing development

② See Section 5.2 for sidewalk design criteria.

Exhibit 5-22 Typical Curbed Roadway (Superelevated Section)



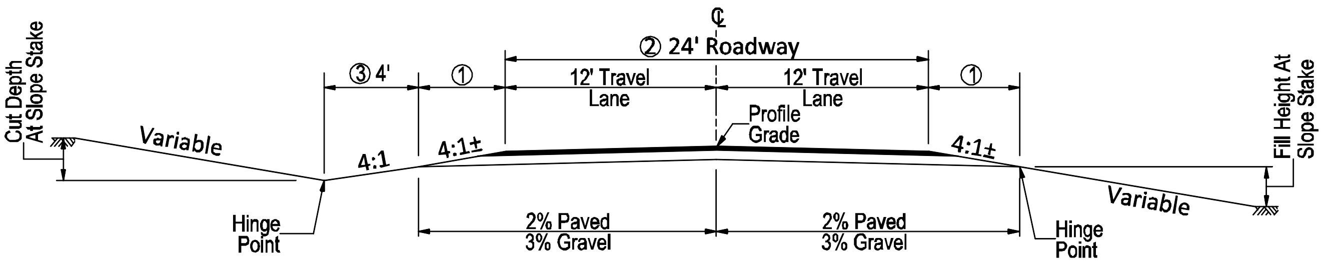
General Note: Dimensions in exhibit will typically apply. See MDT Geometric Design Standards for specific cross section criteria for various conditions (e.g. for cut and fill slopes). See Chapter 3 for details on superelevation.

Superelevation of 4% max applies to low-speed urban streets with V ≤ 45 mph.

① It may be necessary to use separate profiles at the top back of curb to promote positive drainage and to match existing development

② See Section 5.2 for sidewalk design criteria.

Exhibit 5-23 Typical Off-System Roadway (Tangent Section)



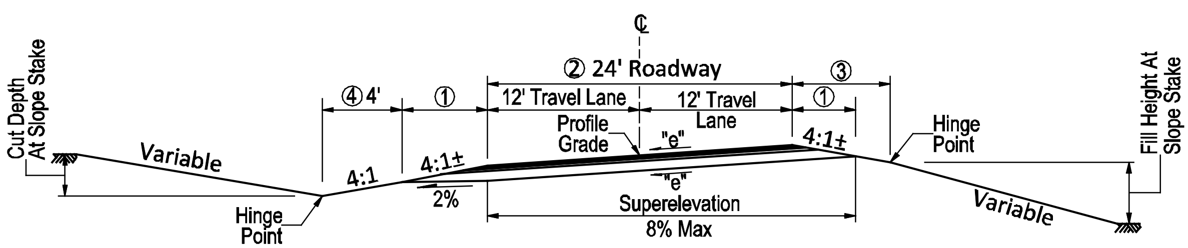
General Note: For ADT > 300, use the criteria for a major collector.

① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② Roadway width may vary; see MDT Geometric Design Standards.

③ Check Chapter 9: Roadside Safety for traversable requirements. For non-traversable ditches, place the tow of the ditch outside the clear zone.

Exhibit 5-24 Typical Off-System Roadway (Superelevated Section)



① Compute subgrade and intermediate surfacing widths to nearest 0.1 foot. Slope is indicated as ± due to rounding.

② Roadway width may vary; see MDT Geometric Design Standards.

③ This distance will be equal to the ① distance on the tangent section (Exhibit 5-23)

④ Check Chapter 9: Roadside Safety for traversable requirements. For non-traversable ditches, place the tow of the ditch outside the clear zone.

5.7 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.

2. Ray, B., E. Ferguson, J. Knudsen, and R. J. Porter. *NCHRP Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets.* Transportation Research Board of the National Academies, Washington, D.C., 2014.

3. AASHTO. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 2011.

4. MDT. *MDT Revised Roadway Width Decision Process*. May 7, 2013.

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7. AASHTO. *Guide for the Development of Bicycle Facilities.* AASHTO, Washington, D.C., 2012.

8. Torbic, D.J., J. Hutton, C. Bokenkroger, K. Bauer, D. Harwood, D. Gilmore, J. Dunn, J. Ronchetto, E. Donnell, H. Sommer III, P. Garvey, B. Persaud, and C. Lyon. *NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips.* Transportation Research Board of the National Academies, Washington, D.C., 2009.

9. Kulash, W. M. and I. M. Lockwood. *Time-saver Standards for Urban Design*, 7.2—5, McGraw-Hill Professional, New York, 2003.

10. Tabler, R. D. *Design Guidelines for the Control of Blowing and Drifting Snow.* Strategic Highway Research Program, Transportation Research Board of the National Academies, Washington, D.C., 1994.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 6

Intersections and Interchanges

September 2016

Contents

Chapter 6

Intersections and Interchanges

Intersections and interchanges are an important part of the transportation system. Intersections create access and provide mobility on a facility; however they are a location of inherent conflict. The operational efficiency, capacity, safety, and cost of the transportation system depend largely upon the design of intersections and interchanges, especially in urban areas.

The primary design objectives of intersections and interchanges are:

- Minimize the potential for and the severity of conflicts among motor vehicles, bicycles, and pedestrians.
- Provide for the convenience, ease, and comfort of all users.
- Provide adequate capacity.
- Examine potential system-wide impacts, especially for new construction.

Chapter 6 discusses the geometric design of at-grade intersections including intersection traffic control, intersection alignment, intersection profile, and turning radii. It provides an overview of lanes at intersections, approaches, multimodal design considerations, speed reduction treatments, as well as alternative forms of intersections, including roundabouts, and interchanges.

Major intersections are intersections involving public roads, often in urban areas. Minor intersections are intersections involving private roads.

The design team should coordinate with the Traffic and Safety Bureau for all work related to major intersections and interchanges.

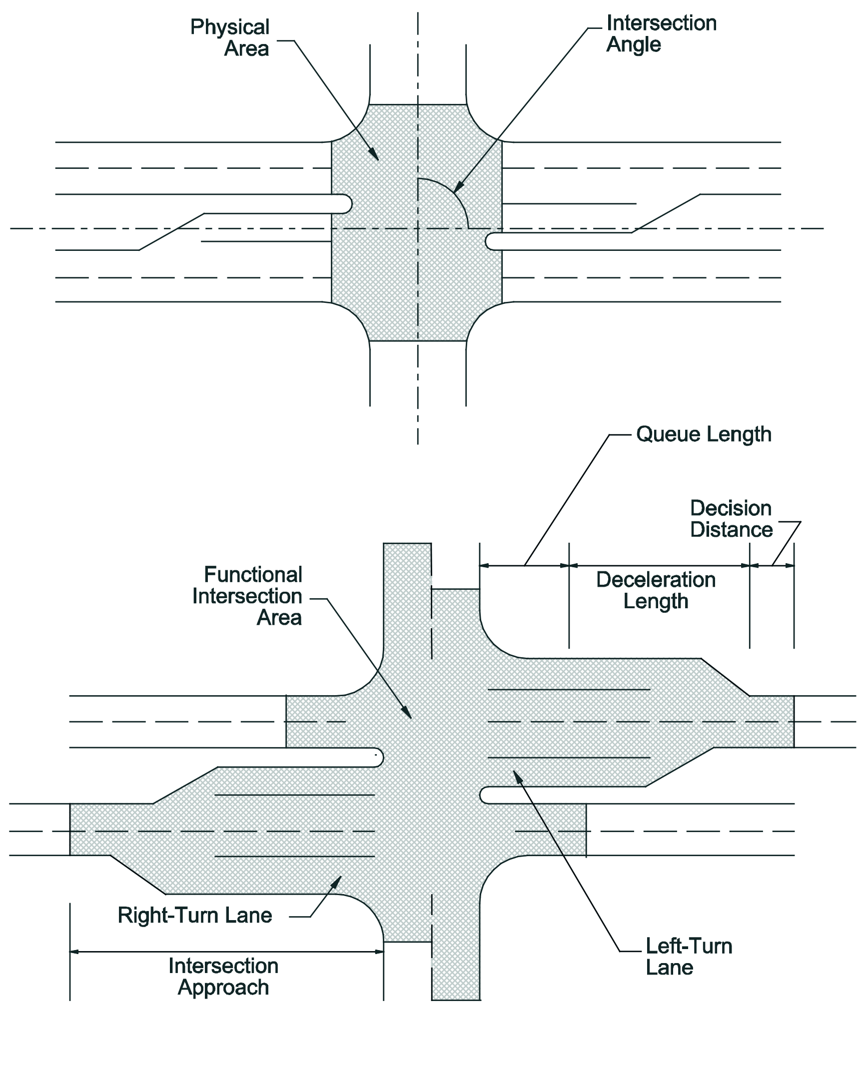
6.1 INTERSECTION DESIGN PRINCIPLES AND APPROACH

Intersections are defined as the general area where two or more roadways join or cross. Exhibit 6-1 illustrates the physical area and the functional area in the intersection. The physical area is the area that facilitates traffic movements, including motor vehicles, bicycles and pedestrians. The functional area extends both upstream and downstream from the intersection to accommodate decision distance, deceleration, queuing, and acceleration.

It should be noted that most of the principles and design guidance provided in this chapter apply to minor rural unsignalized intersections such as public approaches or private and farm field approaches, as well as private driveways in urban settings.

Interchanges include a grade separation of the two crossing roadways, but the same intersection-related principles are also applied to the ramp terminal intersections. Interchange design includes the determination of the appropriate interchange type based on the anticipated travel demand, the placement of ramps, as well as the assessment of ramp-spacing along the freeway corridor to provide a consistent message and expectation to the driver. Additional interchange design considerations are discussed in Section 6.8.

Exhibit 6-1 Physical and Functional Intersection Area



Source: Transportation Research Board (TRB) *(1)*

Intersections are a key feature of the roadway in four respects:

1. **Focus of activity.** Intersections are located in areas with a concentration of travel destinations.

2. **Conflicting movements.** Due to the various directions of travel for each of the various modes (e.g., motor vehicles, pedestrians, and bicycles), conflicting movements arise at intersections.
3. **Traffic control.** Movements at intersections are regulated through traffic control devices, such as yield signs, stop signs, roundabouts, and traffic signals. While aiming to improve safety, the traffic control also creates delay for certain movements.
4. **Capacity.** The capacity of the intersection, as defined by the *Highway Capacity Manual*, is the "maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given period under prevailing roadway, environmental, traffic, and control conditions" *(1)*.

Given the complexity of the concurrent activity at an intersection, additional consideration is needed at intersections in roadway design. The following basic elements should be considered in intersection design:

1. **Human factors.** These can include driving, walking, and cycling habits; the ability of users to make decisions; user expectancy; decision and reaction time; and conformance to natural paths of movement.
2. **Traffic considerations.** These can include classification of each intersecting roadway, design and actual capacities, design-hour turning movements, size and operating characteristics of vehicles, variety of movements (diverging, merging, weaving and crossing), vehicle speeds, transit involvement, crash experience, bicycle movements, and pedestrian movements.
3. **Physical elements.** These can include character and use of abutting property, vertical alignments at the intersection, sight distance, angle of the intersection, conflict area, geometric design features, traffic control devices, lighting equipment, roadside design features, environmental factors, crosswalks, driveways, and access management treatments.
4. **Economic factors.** These can include cost of improvements, effects of controlling or limiting rights-of-way on abutting residential or commercial properties where channelization restricts or prohibits vehicular movements, and energy consumption.

The following subsections will cover the general controls for intersections, including intersection traffic control, intersection alignment, intersection profile, and turning radii.

6.1.1 Intersection Traffic Control

The intersection traffic control type is a decision made by the Traffic and Safety Bureau. This considers the operational tradeoffs and safety of various users of the intersection. The design team should collaborate with the Traffic and Safety Bureau to identify the intersection traffic control type.

At an intersection, the roadway with the higher roadway classification is considered the major roadway. The roadway with the lower roadway classification is considered the minor roadway.

The type of intersection traffic control impacts the capacity of the intersection and the operations of each of the movements. Several types of intersection control are the following:

1. **Yield-controlled intersection.** A yield-controlled intersection is an intersection where one or more legs are controlled by a yield sign and are permitted to enter the intersection without stopping if there are no potentially conflicting vehicles on the major roadway.
2. **Roundabout.** A roundabout is a form of yield-controlled intersection with a generally circular shape, characterized by yield on entry and circulation around a central island.
3. **Stop-controlled intersection.** A stop-controlled intersection is an intersection where one or more legs are controlled by a stop sign.
4. **Signalized intersection.** A signalized intersection is controlled by a traffic signal. The operations of a signalized intersection are impacted by the signal timing of the intersection.

6.1.2 Intersection Alignment

This section provides a general discussion about intersection alignment as a general control for intersection design, as well as guidance on horizontal alignment and intersection angles. Refer to Chapter 3 for additional information on horizontal alignment.

6.1.2.1 Horizontal Curves

An intersection should preferably be located on tangent sections of the intersecting roadways. When a minor road intersects a major road where the major road is on a horizontal curve, the geometric design of the intersection becomes more complicated, particularly for sight distance, turning movements, channelization, and superelevation.

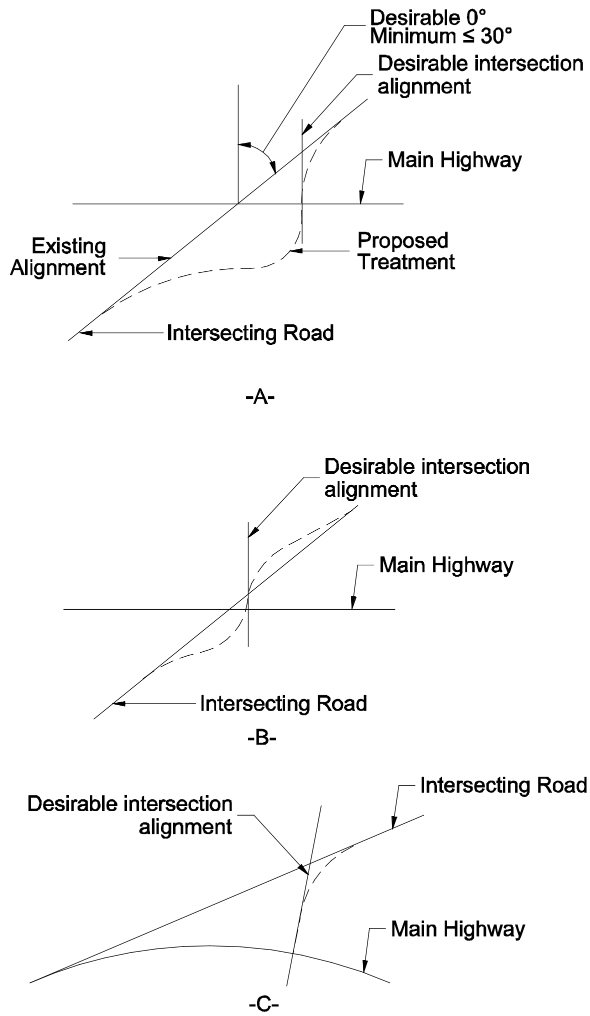
6.1.2.2 Angle of Intersection

It is desirable for roadways to intersect at, or as close to, 90 degrees as practical. Skewed intersections are undesirable for several reasons:

- Vehicular turning movements become more restricted for the acute angle and too fast for the larger angle,
- The accommodation of large trucks for turning may require additional pavement and channelization,
- The exposure time for vehicles and pedestrians crossing the main traffic flow is increased, and
- The driver's line of sight for one of the sight triangles becomes restricted.

The intersection angle should not exceed 30 degrees from perpendicular. Intersections with a skew greater than 30 degrees from perpendicular should be reviewed to identify ways to potentially address the line of sight challenges. It is not always possible to correct intersection angles; the design team should apply the principles of performance-based design by considering the project’s intended outcomes, and documenting the decision process accordingly. For existing intersections, the design team is encouraged to consider realigning the intersection so that its skew is within 30 degrees of perpendicular. Where skew angles greater than 30 degrees are present, the intersection may require geometric improvements, such as realignment, auxiliary lanes, and greater corner sight distance. Exhibit 6-2 illustrates various angles of intersection and potential improvements that can be made to the alignment.

Exhibit 6-2
Treatments for Skewed Intersections



Source: AASHTO *(2)*

6.1.3 Intersection Profile

Reducing an approach grade to meet guidelines may result in a cut section for the approach, which could introduce a snow drifting condition that did not exist previously.

This section outlines design guidance for intersection approach gradient, cross slope transitions, vertical alignment, and intersection sight distance. Refer to Chapter 4 for additional vertical profile information and to Chapter 2 for intersection sight distance guidance.

To allow for the best overall intersection profile design, the mainline horizontal and vertical alignments, as well as its cross section, control the optimum intersection center point and elevations. The design team should aim

Designing minor approaches to meet the approach guidelines may negatively affect right-of-way and access in ways that may not have been intended or considered.

for this desired control point to develop the intersection design (e.g., flatter approach grades, better sight lines, less right-of-way needs, and shorter approach connections). The project context and existing conditions should be considered at the start of a project to ensure that the design will meet the function of an existing approach, without undue adverse effects. Special considerations are needed for all approaches that extend beyond the existing right-of-way to ensure that the approaches do not adversely impact land use, or encroach onto neighboring properties. If approaches have structures close to the highway and/or other physical constraints, and meeting guidelines may not be feasible, this should be documented in the appropriate report.

6.1.3.1 Gradient

Landing areas with a pedestrian crossing should be designed to meet ADA guidance.

The gradient of roadways approaching an intersection should be designed to provide the appropriate drainage, as well as driver expectancy and comfort depending on if the roadway is stop controlled or is free flowing through the intersection. The gradient of a major roadway that is free flowing through the intersection may be designed with a straight grade though the intersection. Typically, drainage from a lower classification of roadway (e.g., collector) should not flow onto a higher classification of roadway (e.g., arterial).

Use of steeper approach slopes does not require a design exception, but should be documented in the appropriate report.

The approach of a roadway leading into an unsignalized rural intersection (e.g., public approaches, private and farm field approaches) is known as a "landing area". The "landing area" is typically created to store stopped vehicles and position the motorist to obtain appropriate sight distance. The intersection should desirably be slightly higher than the approaching roadway, such that the landing area will slope upward toward the intersection on a gradient not to exceed 3 percent. Because of topographical constraints, the landing area may slope downward toward the intersection on a gradient not to exceed 3 percent; however this should be avoided, if practical, due to drainage considerations and to reduce the possibility of a vehicle sliding into the intersection when icy conditions exist.

If a minor road intersects at a superelevated area of the major road, the landing should be designed to avoid a large grade break where the landing meets the intersection. This can be accomplished by providing a vertical curve at the end of the intersection approach, or by introducing small angle breaks within the landing. For landing areas with a pedestrian crossing the gradient should not exceed 2 percent (1.5 percent preferred for design purposes) through the pedestrian crossing.

At a minimum, the length of the landing area toward the intersection should be at least 75 feet for public roads and at least 25 feet for other facilities. When using vertical curves on approaches for public roads, the vertical curve should not encroach onto the landing.

Farm Field Approaches are revocable access points to the highway from agricultural land.

The gradient of the approach beyond the landing area should not exceed 6 percent for public or private approaches unless site constraints require a steeper grade. The gradient of farm field approaches should not exceed 10 percent.

6.1.3.2 Cross Slope Transitions

One or both of the roadways approaching the intersection may need to be transitioned (or warped) to match, or coordinate the cross slope and grade at the intersection. The design team should consider the following:

1. **Stop-Controlled and Yield-Controlled Intersections.** When the minor road is stop-controlled or yield-controlled, the profile grade line and cross slope of the major road will normally be maintained through an intersection, and the cross slope of the stop-controlled or yield-controlled leg will be transitioned to match the major road profile grade. The design team may need to consider alignments through the intersection, if there is potential for a future signal at the intersection.
2. **Signalized Intersection.** At signalized intersections, or potential future signalized intersections, the cross slope of the minor road will typically be transitioned to meet the longitudinal grade (profile) of the major road. If both intersecting roads have approximately equal importance, the design team may want to consider transitioning both roadways to form a plane section through the intersection. Where compromises are necessary between the two major roadways, the smoother riding characteristics should be provided for the roadway with the higher design speeds and/or traffic volumes.
3. **Transition Distance**. The transition from the normal crown of the minor roadway to match the longitudinal grade of the major roadway should be accomplished in a transition distance of 50 feet or more in rural areas. The 50-foot transition distance is also desirable for urban areas but, at a minimum, the transition may be accomplished within the radius of the intersection corner (curb return). See Exhibit 6-3.

Refer to NCHRP Report 659 for additional guidance for the design of driveways.

6.1.3.3 Vertical Profile

Where the profile of the minor road is adjusted to meet the major road, this will result in angular breaks for traffic on the minor road if no vertical curve is inserted. The following options are presented in order from the most desirable to the least desirable; see Exhibit 6-4:

1. **Vertical Curves.** Vertical curves that meet the criteria for stopping sight distance (SSD) as described in Chapter 2, Section 2.8, should be used on the minor road approaches to an intersection. For the approaching legs of an intersection, the vertical curve prior to the approach landing should be designed based on the roadway condition and project context. The grades of the tangents for the vertical curve are the grade of the landing area (G_1) and the profile grade of the minor roadway (G_2); see Exhibit 6-4. The Point of Vertical Tangency (PVT) will be located at the end of the landing (75 feet) from the paved shoulder of the mainline. The PVT can be shifted onto the landing area if the gradient of the landing does not exceed 3 percent.
2. **Sag Vertical Curves.** If constraints do not allow room for sag vertical curves meeting SSD, the next most desirable option is to design the sag for comfort. The length of vertical curve can be determined as follows:

The comfort criteria are based on the comfort effect of change in vertical direction in a sag vertical curve because of the combined gravitational and inertial forces.

Equation 6.1-1

$$L = \frac{AV^2}{46.5}$$

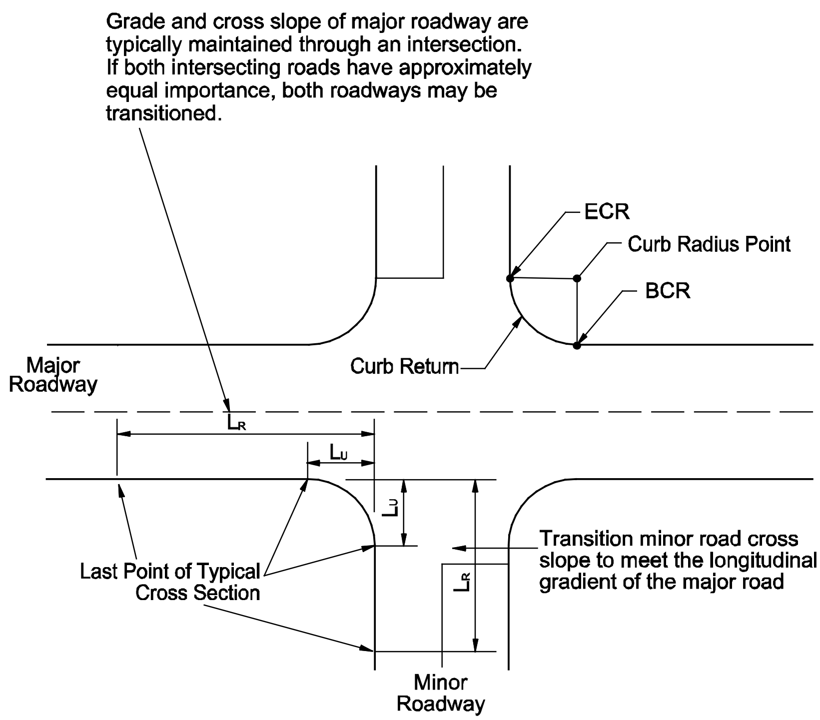
where:

L = length of sag vertical curve, feet

A = algebraic difference between grades, percent

V = design speed, mph

Exhibit 6-3
Pavement Cross Slope Transitions Through Intersections



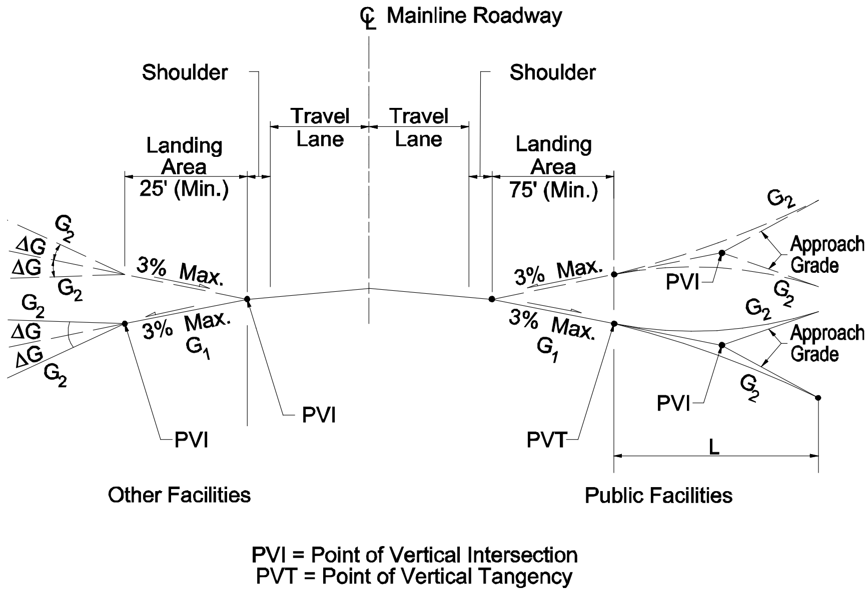
L_R =Transition Length For Rural and Urban Roadways ≥50 ft

L_U =Minimum Allowable Transition Length for Urban Roadways

ECR = End of Curb Return

BCR = Beginning of Curb Return

Exhibit 6-4
Vertical Profiles for Approaches



3. **Angular Breaks.** Angular breaks between the landing area and the approach gradient are typically used on minor approaches; see Exhibit 6-4. For major approaches, it may be impractical to provide vertical curves on the approaches under some restricted conditions where angular breaks are necessary approaching the intersection. Exhibit 6-5 provides the maximum allowable angular breaks for various design speeds. Where angular breaks are used, the minimum distance between successive angle points should be at least 15 feet. The angular break (ΔG), defined as the absolute value of G_2 minus G_1, occurs between the landing area and approach roadway; see Exhibit 6-4.

Exhibit 6-5
Maximum Change in Grades without a Vertical Curve

Design Speed (mph)	Crest Angular Breaks (ΔG)	Sag Angular Breaks (ΔG)
20	7.5%	4.8%
25	5.4%	2.7%
30	3.5%	1.7%
35	2.4%	1.2%
45	1.8%	0.9%
50	1.4%	0.7%
55	1.1%	0.5%
60	0.9%	0.4%

Note: Design speed applies to the roadway with the angular break. Typically, this will be the minor roadway.

6.1.3.4 Intersection Sight Distance

The design team needs to consider the effect that the intersection profile and alignment will have on intersection sight distance. Landings with steep upgrades into the intersection may put the driver's eye below or in line with roadway appurtenances (e.g., guardrail, signs). Also, large skewed intersections may require some drivers to look back over their shoulder to view conflicting traffic from the crossing street. The effect of these skews on intersection sight distance depends on the type of traffic control used at the intersection. For more information on intersection sight distance, see Chapter 2, Section 2.8.

6.1.4 Turning Radii

For intersections where trucks, pedestrians, traffic signals, turning lanes or uncommon intersection configurations are present, the Traffic and Safety Bureau should be consulted.

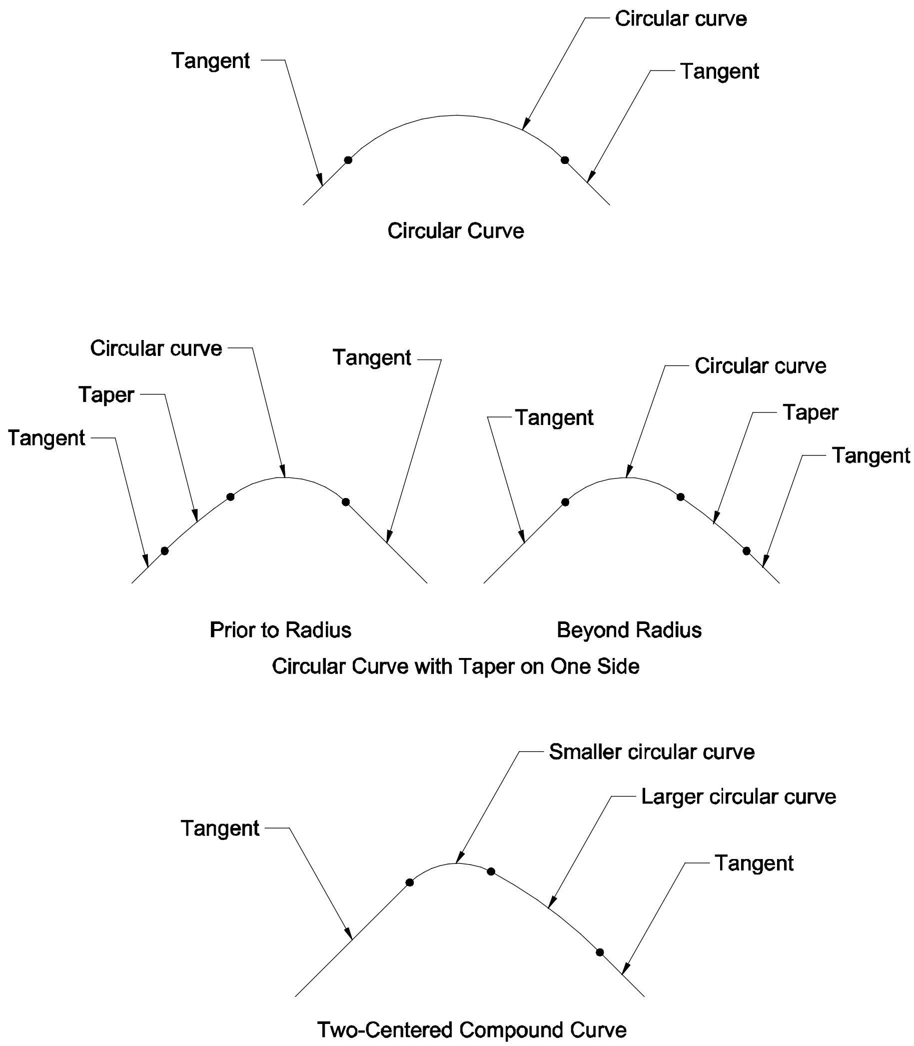
Typically, the turning radii at intersections will consist of circular curve radii. The design team should check the intersection with the design vehicle turning template to ensure the design is adequate, as well as consider the crossing distance for pedestrians and bicycles across the intersection. See Chapter 2, Section 2.2.3.4 for additional guidance regarding the design vehicle for the Interstate and Primary systems.

As illustrated in Exhibit 6-6, to accommodate right-turning vehicles at an intersection, one of the following edge of pavement or curb lines may be selected:

- Circular radius
- Compound curve (two- or three-centered)
- Circular radius with entering and/or exiting taper(s)

While the circular curve is the easiest to design and construct, and therefore is the most common, the design team should consider the benefits of the compound radii configuration or a circular radius with tapers. Circular radius curves often require greater intersection pavement area and also result in longer crossing distances for pedestrians, compared to compound curves or a radius with tapers.

Exhibit 6-6
Curb Returns



Source: AASHTO *(1)*

6.2 LANES AT INTERSECTIONS

6.2.1 Turn Lane Guidelines

When considering a right-turn lane on a through roadway, specific attention should be given to visibility on the side street. Decelerating vehicles in the turn lane can create a moving sight obstruction. The stop line for the side street should be placed so that the vehicles on the side street can see the through vehicles on the mainline without the obstruction of the right-turning vehicles along the mainline. Channelizing islands (painted or raised) can be used to control proper placement of stopped and decelerating turning vehicles.

When establishing turn lanes, the design team needs to consider access to and from private properties on the legs to the intersection. Along major roads, accesses should not be located along the length of the turn lanes. Along the minor roadway, traffic activity at access points along the minor road may induce queue spillback onto the major road. In absence of access control resolutions, it is recommended to place accesses at appropriate locations as indicated in Section 6.3.

Coordinate with the Traffic and Safety Bureau when considering the addition of a turn lane.

6.2.2 Design of Turn Lanes

For the design of turn lanes (e.g., widths, lengths, types), coordinate with the Traffic and Safety Bureau.

6.2.2.1 Widths

The following will apply to turn lane widths:

1. **Lane Widths**. Typically, the width of any turn lanes at an intersection is the same as that of the adjacent through lane, or is based on the design vehicle. In rare cases, it may be justified to provide a narrower width (e.g., restricted right-of-way).
2. **Shoulder.** For shoulders adjacent to turn lanes, the design team should consider the needs for curbed and uncurbed facilities, while maintaining the same as the normal shoulder width for the approaching roadway.
3. **Cross Slope**. The cross slope for a turn lane will typically be the same as the adjacent through lane.

6.2.2.2 Turn Lane Lengths

At high volume locations, the length of the turn lane should also include storage of turning vehicles.

For special conditions, for example railroad crossings, additional storage may be provided or a wider shoulder.

The length of a right-turn or left-turn lane at an intersection should allow for safe vehicular deceleration of turning vehicles. For urban facilities, it may be impractical to provide a turn lane length that completely accommodates the appropriate deceleration within the length of the turn lane. Therefore, the turn lane may be designed to only provide sufficient distance for storage at urban intersections. For rural facilities, the primary consideration is deceleration distance. To determine the turn lane length, the design team should consider the following:

1. **Taper.** For tapers, a straight-line taper is typically used at the entrance of the turn lane. The taper rate is determined by the design speed. Short, straight line tapers should not be used on curbed urban streets, because the natural path of vehicles may result in vehicles hitting the leading end of the taper. Where a partial tangent taper is used, the tangent section should be about two-thirds of the total length.

2. **Deceleration.** The deceleration distance is the distance a vehicle needs to decelerate from the design speed of the traveling roadway to the back of the anticipated queue (e.g., storage) at the intersection.
3. **Storage.** The storage length for turn lanes should be sufficient to store the number of vehicles likely to accumulate during the design hour.

6.2.3 Through Lanes

The number of continuous through lanes at intersections provides continuity along a corridor. For example, when a motor vehicle enters a corridor and uses it as a through route, then the lanes should be consistent throughout the corridor and vehicles should not be required to change lanes where lanes are added and removed. The lane widths should also be consistent throughout. However, it may not always be possible to provide continuous through lanes due to site constraints. If a traffic study shows that the traffic distribution supports the dropping of a lane at an intersection, overhead signage is encouraged to inform the motorists of these lane changes. More information on lane widths can be found in Chapter 5, Section 5.2.

6.3 APPROACHES

An approach is the portion of a roadway, accessing a state highway from abutting property that is within the highway right-of-way. The design team should apply the same design principles for the design of private approaches as for rural unsignalized intersections (refer to Section 6.1). In construction projects, the area in which work is needed outside of the right-of-way to adequately provide the access is also considered as part of the approach.

In absence of access control resolutions, it is recommended to locate accesses at least 100 feet, or preferably 150 feet, from the intersection for private accesses and 300 feet for public accesses.

When designating approaches, the design team should consider the following:

1. **Limited Access Control Projects.** The Right-of-Way Bureau will provide the design team with the "Limited Access Control Recommendations," which provides the designations for all approaches within Limited Access Control.
2. **Regulated Access Projects.** The Right-of-Way Bureau will not provide the design team with recommendations of designation for approaches. The design team will make this determination from "existing use" or right-of-way agreements, if applicable.

Refer to *MDT's Approach Manual for Landowners and Developers* for MDT's criteria on approaches, in addition to the information provided in this chapter for minor stop-controlled intersections *(2)*. This publication has been prepared by MDT's Traffic and Safety Bureau in conjunction with the Right-of-Way Bureau and the Maintenance Division. This document is provided at the following link on the MDT website.

MDT Approach Manual for Landowners and Developers

These regulations are adopted and issued according to the authority granted to MDT under current Montana Law. Unless otherwise provided or agreed to, they apply to all Federal-Aid System and other MDT jurisdiction routes. The frequency, proper placement and construction of points of access to highways are critical to the safety and capacity of those highways. These regulations are intended to provide for reasonable and safe access to highways while preserving their safety and utility to the maximum extent practical. These regulations are not intended to alter or reduce existing or future access control or access limitations, nor are they intended to alter or supersede access which has been agreed to by appropriate written contract with MDT.

More information regarding approaches can be found in Chapter 2, Section 2.7.

6.4 MULTIMODAL DESIGN CONSIDERATIONS

Intersections should be designed and operated to enable safe use and access for people of all ages and abilities using all modes of travel, including walking, cycling, driving, and riding transit. Intersections create increased exposure for all modes, and create potential conflict locations for the users. The design team should understand the context and consider trade-offs when refining the intersection geometry.

Pedestrian facilities should allow people to cross safely on foot or with an assistive device. In addition, pedestrian facilities should be designed to be accessible to all users, regardless of ability. The United States Access Board provides additional resources on accessibility and specific requirements for Accessible Public Rights of Way *(3).*

Bicycle facilities should provide safe crossings for people riding bicycles, with consideration for the potential conflict areas between bicyclists and turning motor vehicles.

Chapter 7 of this manual describes the various treatments and the integration of multimodal design in the overall design process, including at intersections. It also addresses accessibility as it relates to special consideration given to pedestrians with disabilities including accommodating pedestrians with vision or mobility impairments.

6.5 SPEED REDUCTION TREATMENTS

Downstream intersection operations (e.g. queuing, deceleration, turning vehicles) and geometry may create a condition that requires drivers to reduce their speed. At an intersection, a driver is required to perceive and comprehend a greater variety of situations than when driving on a roadway segment. Therefore, speed reduction treatments in advance of or at the intersection may be beneficial to the operations and safety of the roadway and intersection. This is particularly the case for transitional areas, where a driver may be moving from a high-speed rural environment into an urban area with lower speeds and the potential for more pedestrians and bicyclists. Speed reduction treatments can help make drivers aware of the approaching change in environment and encourage drivers to reduce their speeds as they enter the new area. Speed transitions should be considered between the roadway segment and the intersection influence area to allow drivers the opportunity to react to the change in conditions and adjust the speeds accordingly.

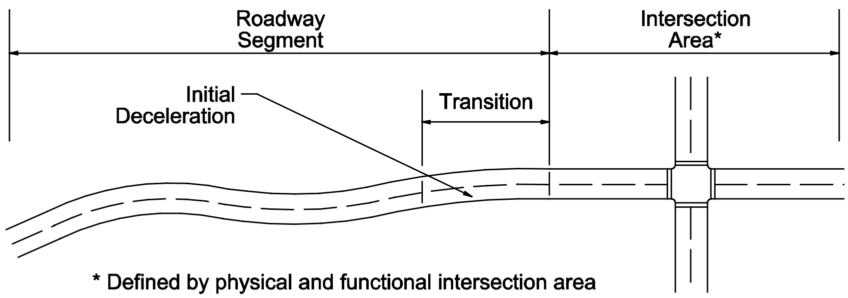
Exhibit 6-7 illustrates a schematic of the roadway segment and intersection speed relationships. The intersection influence area can be determined through geometric or operational influences.

Decisions regarding speed reduction treatment types and directions should be coordinated with the Traffic and Safety Bureau to integrate these treatments into the roadway design.

Geometric influences are where the typical section of the roadway segment is modified in advance of the intersection.

Operational influences are due to traffic operations such as queuing, lane changes, merging, or acceleration/deceleration.

Exhibit 6-7
Schematic of Roadway Segment and Intersection Speed Relationship



Source: TRB *(4)*

When considering a speed reduction treatment, the design team should evaluate the applicability, cost, implementation considerations, and potential to effectively reduce speeds and increase safety. This may include considering the following questions *(4)*:

- What is the target speed?
- Where, and by how much, should the speeds be reduced?
- What information is available about each treatment?
- Has there been any past research conducted on that particular treatment? Was the treatment effective? Were there any side effects of the treatment?

The performance-based design framework discussed in Chapter 1, Section 1.2 may provide guidance for identifying the need and purpose of a speed reduction treatment.

Examples of speed reduction treatments include the following:

- Dynamic warning signs,
- Transverse pavement markings,
- Rumble strips (note that there are noise implications with rumble strips),
- Wider longitudinal pavement markings,
- Approach curvature,
- Landscaped medians or splitter islands,
- Reduced lane width,
- Visible shoulder treatments, and
- Roadside design features.

Speed reduction treatments should be selected and designed specific for the project context and project purpose. The design team should coordinate with the

Traffic and Safety Bureau to gather speed, operations, and crash history to fully understand the needs of the facility and potential mitigation options. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections* provides additional design considerations for implementing speed reduction treatments and the potential effectiveness of various types of treatments *(4)*.

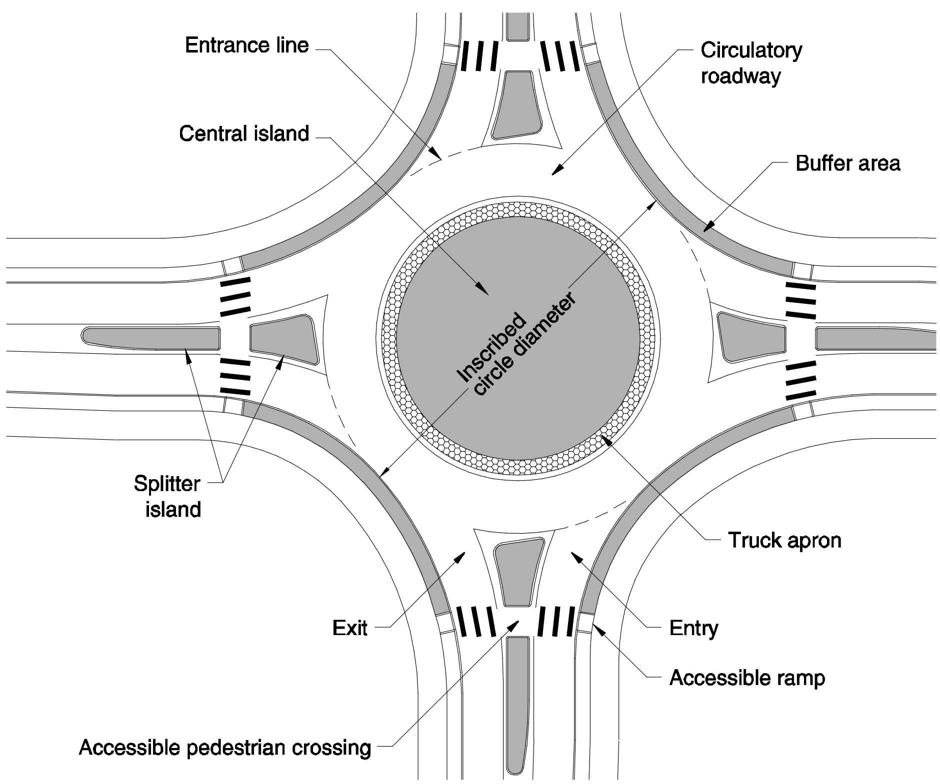
6.6 ROUNDABOUTS

This section provides an overview of roundabout design and application, which is consistent with the national guidance provided in *NCHRP Report 672: Roundabouts: An Informational Guide, Second Edition (5)*. The design team should coordinate with the Traffic and Safety Bureau regarding geometric design as well as operational and safety aspects associated with roundabouts. The design team should understand key design and operational features of a roundabout.

6.6.1 Overview and Considerations

Roundabouts are a generally circular intersection in which traffic travels counterclockwise around a central island and in which entering traffic yields to the circulating traffic. Exhibit 6-8 illustrates the key characteristics of a roundabout. The key design and operational features of a roundabout include channelized approaches, aprons to accommodate appropriate design vehicles, geometric curvature and features to induce desirable vehicular speeds, entry flares, splitter islands, pedestrian crossings on the legs, and no parking within the circulatory roadway.

Exhibit 6-8
Key Roundabout Characteristics



Source: TRB *(5)*

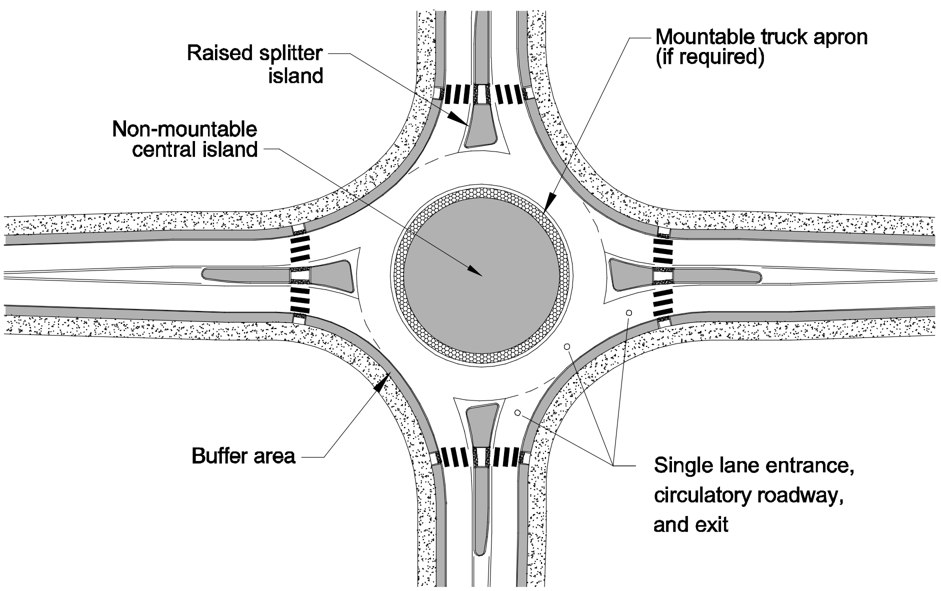
6.6.2 Types

There are various types of roundabouts in the United States. The three most common types include the single-lane roundabout, the multilane roundabout, and the mini-roundabout. Each of these types is further described below.

6.6.2.1 Single-Lane Roundabout

The single-lane roundabout is characterized as having a single-lane entry and exit at all legs and one circulatory lane. Exhibit 6-9 shows the key features of a typical single-lane roundabout, including raised splitter islands, a non-traversable central island, crosswalks, and a truck apron. They have larger inscribed circle diameters compared to mini-roundabouts, and have non-traversable central islands.

Exhibit 6-9
Example of a Single-Lane Roundabout

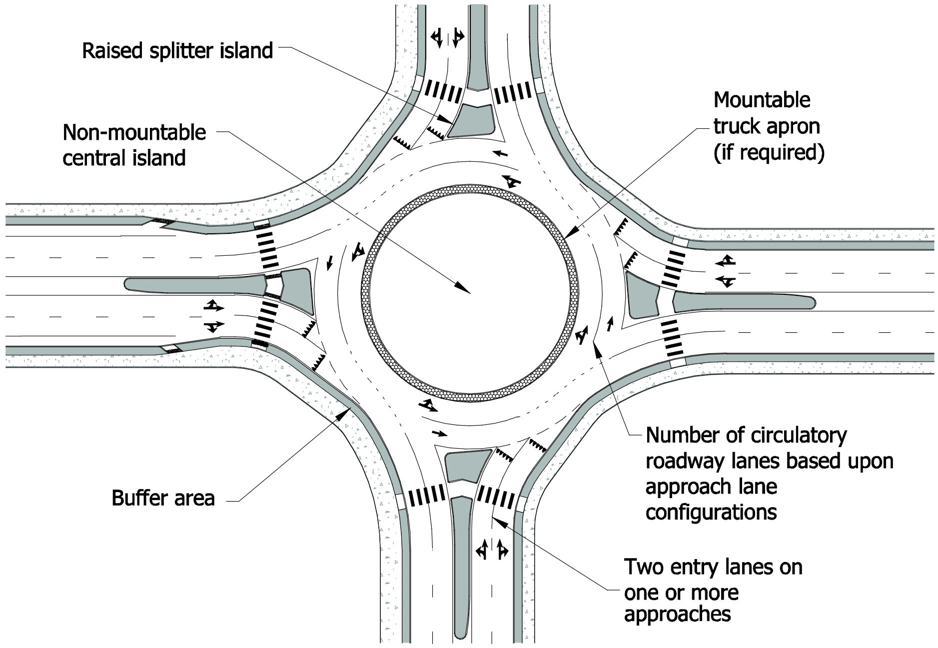


Source: TRB *(5)*

6.6.2.2 Multilane Roundabout

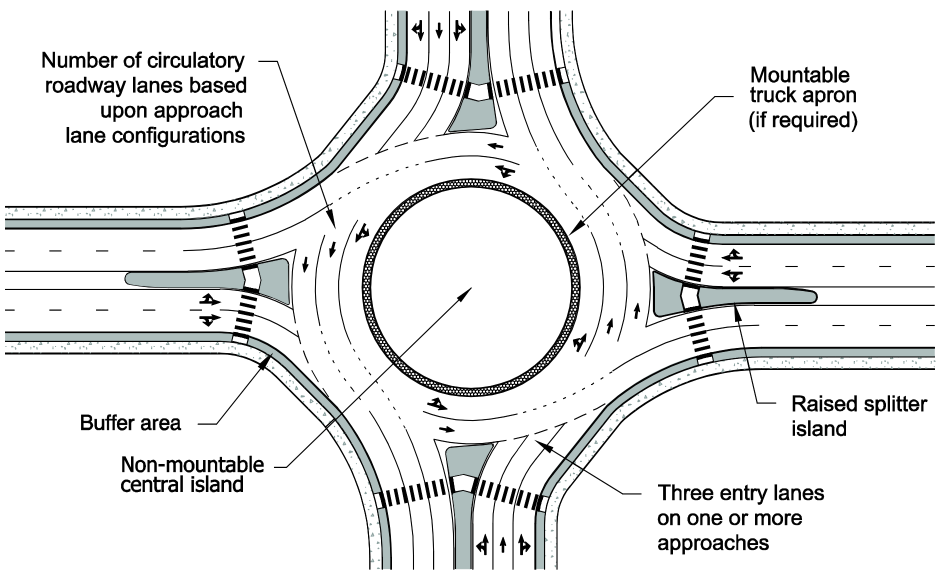
Multilane roundabouts have at least one entry and/or exit with two or more lanes, requiring wider circulatory roadways to accommodate more than one vehicle traveling side by side. Exhibit 6-10 and Exhibit 6-11 illustrate the features of a typical two-lane roundabout and a three-lane roundabout, respectively. The speeds at the entry, on the circulatory roadway, and at the exit are similar or may be slightly higher than those for the single lane roundabouts. The geometric design will include raised splitter islands, truck apron, a non-traversable central island, and appropriate entry path deflections.

**Exhibit 6-10
Example of a Two-Lane Roundabout**



Source: TRB *(5)*

**Exhibit 6-11
Example of a Three-Lane Roundabout**

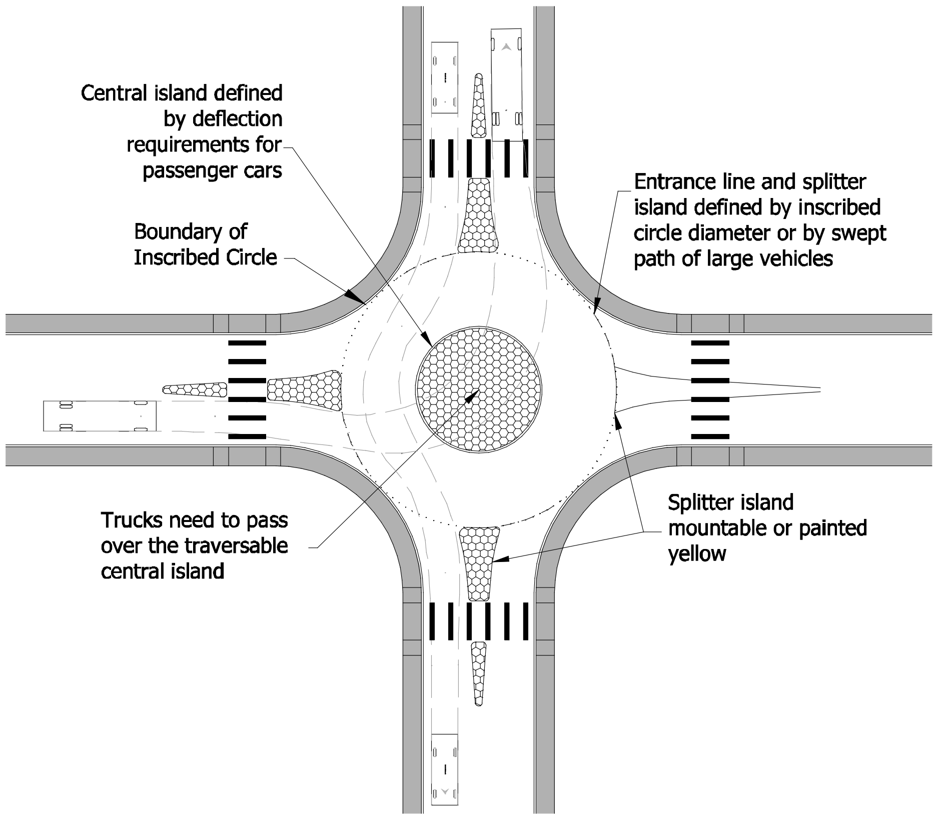


Source: TRB *(5)*

6.6.2.3 Mini-Roundabout

Mini-roundabouts are small roundabouts with a fully traversable central island. They are most commonly used in low-speed urban environments with average operating speeds of 30 miles per hour or less. Exhibit 6-12 shows the features of typical mini-roundabouts, including the fully traversable central island, the striped or traversable splitter islands, and the minimal additional pavement required. Where conventional roundabout design is infeasible due to right-of-way constraints, a mini-roundabout may be a less impactful alternative.

Exhibit 6-12
Example of a Mini-Roundabout



Source: TRB *(5)*

6.6.3 Design Principles and Objectives

A well-designed roundabout achieves the principles of speed management, lane arrangement, appropriate path alignment, appropriate design vehicle, accommodates multimodal users, and considers sight distance and visibility.

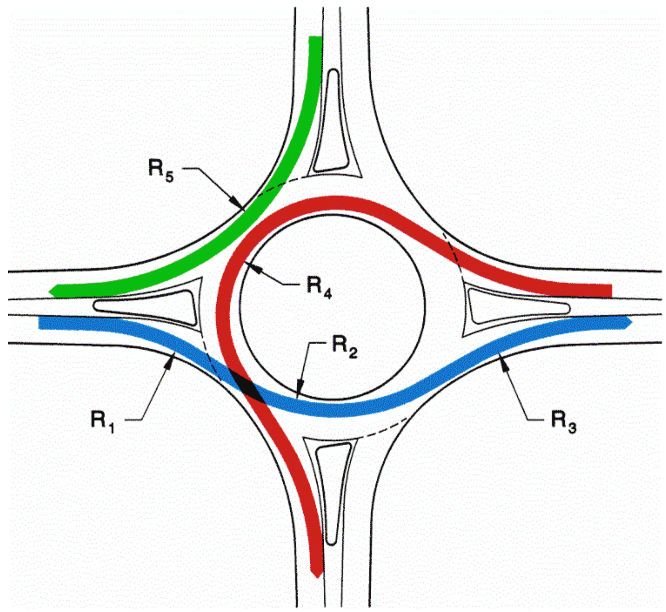
1. **Lane arrangement.** Upon identifying the number of lanes needed for the approaches and the circulatory roadway of the roundabout, the lane assignments should be determined based on operational needs for existing and design year conditions. Appropriate lane arrangement at a multilane roundabout means that a motorist chooses an approach lane based on the desired destination—the driver should not have to change lanes in the circulatory roadway. Interim designs with smaller lane configurations can be implemented in the case that design year traffic volumes are significantly greater than existing needs.
2. **Speed management.** The roundabout should reduce vehicle speeds upon entry and achieves consistency in the relative speeds between conflicting traffic streams by requiring vehicles to negotiate the roundabout along a curved path.

   The fastest path is the smoothest, flattest path possible for the single vehicle through a roundabout, in the absence of other traffic and lane markings. The

The fastest path methodology represents a theoretical attainable speed. Actual speeds may differ based on roadway characteristics and driver behavior.

fastest path for a given roundabout geometry determines the theoretical attainable entry speed through this roundabout for design purposes. The five critical path radii that should be considered include the entry path radius (R_1), the circulating path radius (R_2), the exit path radius (R_3), the left-turn path radius (R_4), and the right-turn path radius (R_5), as shown in Exhibit 6-13. Calculations for these radii and the fastest path can be found in *NCHRP Report 672 (5)*.

Exhibit 6-13
Vehicle Path Radii



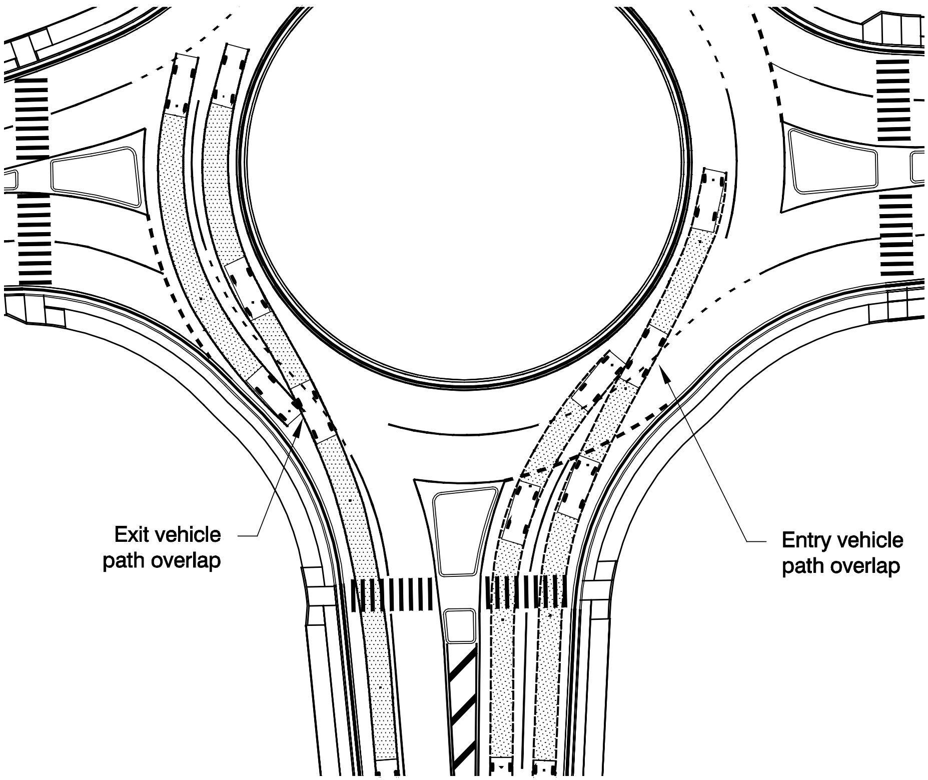
Source: TRB *(5)*

Entering design speeds based on a theoretical fastest path of 20 to 25 miles per hour are recommended at single-lane roundabouts. At multilane roundabouts, maximum entering design speeds of 25 to 30 miles per hour are recommended based on a theoretical fastest path assuming vehicles ignore all lane lines. These speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approaching roadways. As a result, speed management is often a combination of managing speeds at the roundabout itself and managing speeds on the approaching roadways. On approaching roadways with multiple approach curves, speeds can be reduced by 10 to 15 miles per hour with each curve. Splitter islands are also implemented for speed management, and their lengths are approximately two-thirds of the deceleration distance for an approach.

3. **Appropriate path alignment.** The natural path of a vehicle is the path of how a vehicle will naturally travel through the roundabout, given the presence of traffic in all approach lanes, particularly at a multilane roundabout. The key considerations include providing appropriate alignment by arranging curve radii in conjunction with tangent sections to systematically slow vehicles approaching a roundabout. This geometry positions the motorist in the lane at the entry to align with the correct receiving circulatory lane (similar approach applies for the exits). For the safety and operation of the roundabout, the natural paths of adjacent vehicles should not overlap. In

multilane roundabouts, inadequate entry path or exit path alignment may cause path overlap. Path overlap can create safety issues and can reduce the driver's ability to navigate through the roundabout. Exhibit 6-14 shows areas of possible path overlap at a multilane roundabout with inadequate entry path or exit path alignment.

Exhibit 6-14
Path Overlap at a Multilane Roundabout with Inadequate Path Alignment



Source: TRB *(5)*

4. **Design vehicle.** The design vehicle is the largest vehicle to likely use the roundabout. The design vehicle should be determined based on the approaching roadway types and the surrounding land use characteristics, and in consultation with the local agency or MDT. The design vehicle will impact the selection of curb-to-curb widths and turning radii. Truck aprons should be designed to accommodate the pathways of larger vehicles (e.g., trailer wheels on the mountable truck apron) with no encroachment onto the central island. Depending on the roadway, consideration should be given to accommodate non-standard vehicles, such as oversized and overload vehicles. For example, the design team may make objects such as signs removable at roundabouts or provide a bypass for these vehicles. Other treatments for oversized and overload vehicles may include thickened concrete curbs, island caps, and sidewalks. Soil treatments may also be used to create a durable surface outside of the roundabout corner radii to accommodate oversized and overload vehicles. The roundabout design should be refined to accommodate the appropriate design vehicles by collaborating with the public and Motor Carrier Services.

Urban applications of roundabouts near interchanges pose new challenges with designing for multimodal users. Think of design in three dimensions rather than simply two.

Island caps are concrete caps in the medians of splitter islands.

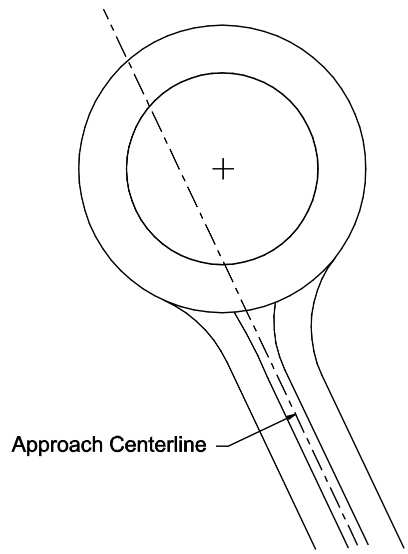
5. **Multimodal users.** The roundabout should be accessible to and usable by all users. More information on designing for multimodal users can be found in Chapter 7.
6. **Sight distance.** While the principles of sight distance at a roundabout are the same as those for a conventional intersection, there are several new considerations in assessing stopping sight distance and intersection sight distance at roundabouts. The intersection angle between consecutive entries should allow for a view of oncoming traffic from the immediate upstream entry. The design team needs to coordinate with the landscaping design to ensure appropriate sight distance needs. More information regarding sight distance calculations at roundabouts can be found in Chapter 2, Section 2.8.

6.6.4 Design Considerations

The design of a roundabout involves optimizing three design decisions: (1) size, (2) position, and (3) the alignment of the approach legs. There are numerous possible combinations of each element, each with its own advantages and disadvantages. Selection of the optimum combination will often be based upon the constraints of the project site, balanced with the ability to adequately control vehicle speeds (entering, through, and exiting the roundabout), accommodate heavy vehicles, and meet the overall design objectives. The following includes design considerations based on basic principles for intersection designs, as applied to roundabout design:

1. **Size.** The selection of the inscribed circle diameter (outer curb diameter) is generally the first step in the design process. The inscribed circle diameter is determined by the number of lanes needed and the design vehicle.
2. **Position.** The position of the roundabout can be determined by creating a conceptual design of the roundabout and placing it on an intersection map. Moving the roundabout around on the map can help to identify and evaluate impacts to existing topography, facilities, and right-of-way while allowing approach alignments to achieve appropriate speed control.
3. **Approach Alignment.** The alignment of the approach legs plays an important role in the design of a roundabout. The alignment affects the amount of speed control that is achieved, the ability to accommodate the design vehicle, and the visibility angles. There are three alignment options: (1) alignment through the center of roundabout, (2) alignment to the left of center, and (3) alignment to the right of center. There are advantages and trade-offs for each alignment. MDT recommends an offset alignment to the left of the center of the inscribed circle. This design allows for increased deflection which will help to control entry speeds. A left-offset alignment also allows for better accommodation of large trucks in roundabouts with small inscribed circle diameters by allowing for a larger entry radius. A left offset alignment is shown in Exhibit 6-15.

Exhibit 6-15
Left Offset Alignment



Source: TRB *(5)*

4. **Pedestrian design considerations.** Three important components of pedestrian facilities at roundabouts include sidewalks, crosswalks, and signalized crossings. Sidewalks at roundabouts should be set back from the edge of the circulatory roadway with a buffer area. This provides a more comfortable facility for pedestrians, while also discouraging pedestrians from crossing the circulatory roadway and guiding pedestrians with vision disabilities to the designated crosswalks. The buffer area also provides an area for snow storage. Roundabouts in urban environments should have sidewalks, and those in rural environments should have sidewalks if there are sidewalks along the corridors leading up to the roundabout or if sidewalks are being considered in the future. Consideration should be made to accomplish the grading for future sidewalks and buffer areas with the initial roundabout construction. Crosswalks assist pedestrians in crossing the legs of the approaches of the roundabout and should balance the needs for pedestrian convenience, pedestrian safety, and roundabout operations. MDT has the following guidance regarding the design of crosswalks at roundabouts:

   - Crosswalks are placed approximately 40 to 50 feet back from the yield line. Consideration can be given to greater distances (approximately 60 to 80 feet) for the exit side to minimize the possibility of queues upstream of the crosswalk extending back into the circular roadway.
   - Multilane roundabouts require signalization of the pedestrian crossings, in the form of an actuated pedestrian hybrid beacon.

In addition, similar to conventional intersections, roundabout approach grades should have a 2-percent maximum grade (preferably 1.5 percent to allow for construction tolerance) at the crosswalk.

5. **Bicycle design considerations.** The roundabout can be designed for bicyclists to traverse the intersection as a vehicle or as a pedestrian. For a bicyclist to use the roundabout as a vehicle, consideration should be given to the transition from an upstream bicycle lane to merging into the vehicular flow, as bicycle lanes should not be located within the circulatory roadway of roundabouts. A bicyclist may also use the shared-use path at the roundabout as a pedestrian, and bicycle ramps are typically provided to allow access to the sidewalk or shared use path at the roundabout.
6. **Parking considerations.** Parking should not be allowed in the circulatory roadway of a roundabout, as it may interfere with the efficiency and safety of roundabout operations. Parking may be accommodated in the deceleration area, unless it impedes sight lines for drivers and pedestrians.
7. **Bus stop locations.** Bus stops should not be located in the circulatory roadway. There are various design considerations for bus stop locations on the near side and the far side of the roundabout, such as entry and exit speeds, visibility of pedestrians, potential queuing behind buses during passenger loading, and merging and diverging from traffic when using a bus pull-out.
8. **Grade of circulatory roadway.** The typical roadway has a 2-percent cross slope down towards the outside of the roadway. If the entire roundabout must be tilted due to topography, grades are allowed up to 2 percent across the overall roundabout plane.
9. **Treatments for high-speed approaches.** Roundabouts located in rural areas with higher roadway speeds than urban areas need to make approaching drivers aware of the roundabout and encourage decelerating to the appropriate speeds. An alignment with successive curves may be considered for high-speed approaches. An emphasis should be placed on visibility, curbing, splitter islands, cross sectional elements, and other features to increase roundabout visibility such as landscaping and the mounding of the central island.
10. **Right-turn bypass lanes.** A right-turn bypass lane can improve the traffic operations of a single-lane roundabout without upgrading the intersection to a multilane roundabout, depending on the right-turn volumes at the intersection. A right-turn bypass lane can be designed as a full bypass with an acceleration lane in the exiting lane, or a partial bypass with a yield at the exit leg. There are tradeoffs for introducing a bypass lane, and implementation of a bypass lane may produce additional challenges for bicyclists and pedestrians due to the geometry and generally higher speeds associated with bypass lanes.
11. **Vertical considerations.** Vertical considerations, such as profiles, superelevation, and approach grades, are needed to accommodate trucks to prevent overturning at a roundabout.
12. **Materials and design details.** The materials and design details of curb types, the circulatory roadway pavement types, and the truck apron material should be selected in considering the overall design of the roundabout.

13. **Drainage.** Inlets should be placed on the outer curb line of the roundabout, as the circulatory roadway slopes away from the central island. Drainage and detention basins can use buffer areas and splitter islands (depending on the size), and discourage flow from the central island across the circulatory roadway. Consideration should be given to the locations of low points and the relative location of crosswalks.
14. **Maintenance, including snow removal and storage.** Snow is typically plowed to the outside of the roundabout, and the drainage should be facilitated as described above.

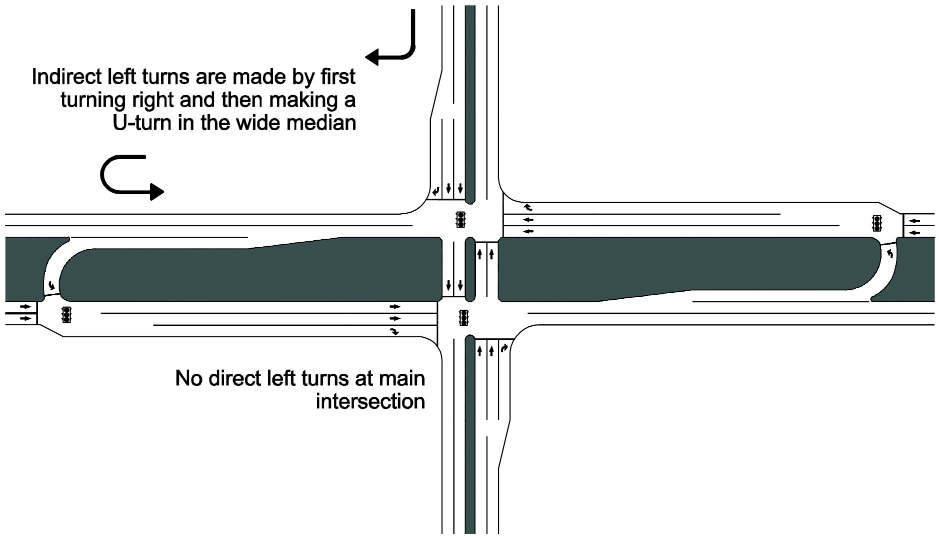
6.7 ALTERNATIVE INTERSECTIONS AND INTERCHANGES

This section includes a discussion on alternative intersections, such as Median U-turn Intersections, Restricted Crossing U-turn Intersections, Displaced Left-Turn Intersections, and Diverging Diamond Interchanges. For more information, the design team should refer to the *Federal Highway Administration (FHWA) Alternative Intersection Information Guides (6, 7, 8, 9)*.

6.7.1 Median U-Turn Intersections

The Median U-Turn (MUT) intersection is also known as the Median U-Turn Crossover, and sometimes referred to as a boulevard turnaround, a Michigan loon, or a Thru-Turn Intersection. The MUT intersection replaces direct left-turns at an intersection with indirect left-turns using a U-turn movement in a wide median, as shown in Exhibit 6-16. By eliminating left-turns on all approaches of the intersection, the MUT intersection reduces the number of traffic signal phases and conflict points at the main crossing intersection. More information can be found in the *FHWA Median U-Turn Informational Guide (6)*.

Exhibit 6-16
Key Characteristics of a MUT Intersection

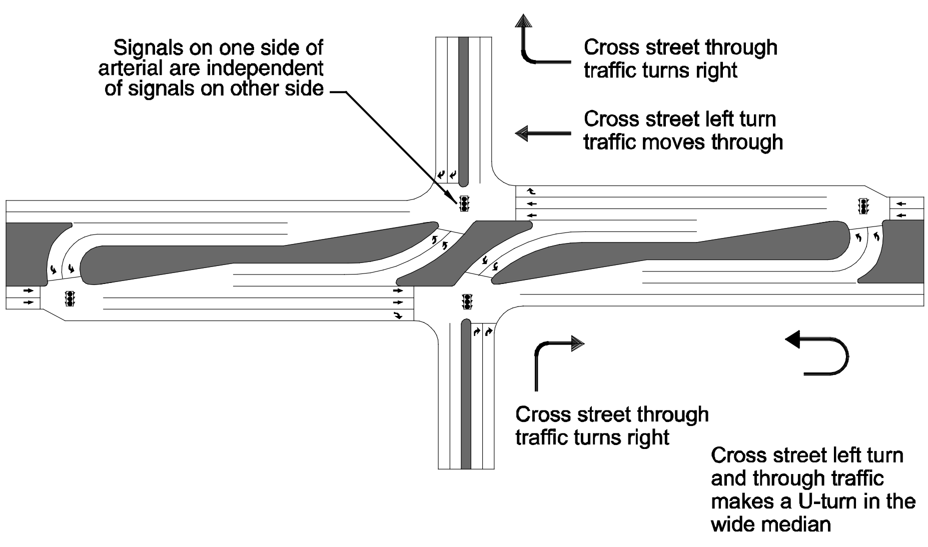


Source: FHWA *(6)*

6.7.2 Restricted Crossing U-Turn Intersections

The Restricted Crossing U-Turn (RCUT) intersection is also known as a superstreet intersection, a J-turn intersection, or a synchronized street intersection. The RCUT intersection replaces direct left-turns and through movements from cross street approaches at an intersection with indirect left-turns using a U-turn movement in a wide median. RCUT intersections can be signalized, stop-controlled, or merge- or yield-controlled. A signalized RCUT intersection is shown in Exhibit 6-17. More information can be found in the *FHWA Restricted Crossing U-Turn Informational Guide (7)*.

Exhibit 6-17
Key Characteristics of a RCUT Intersection

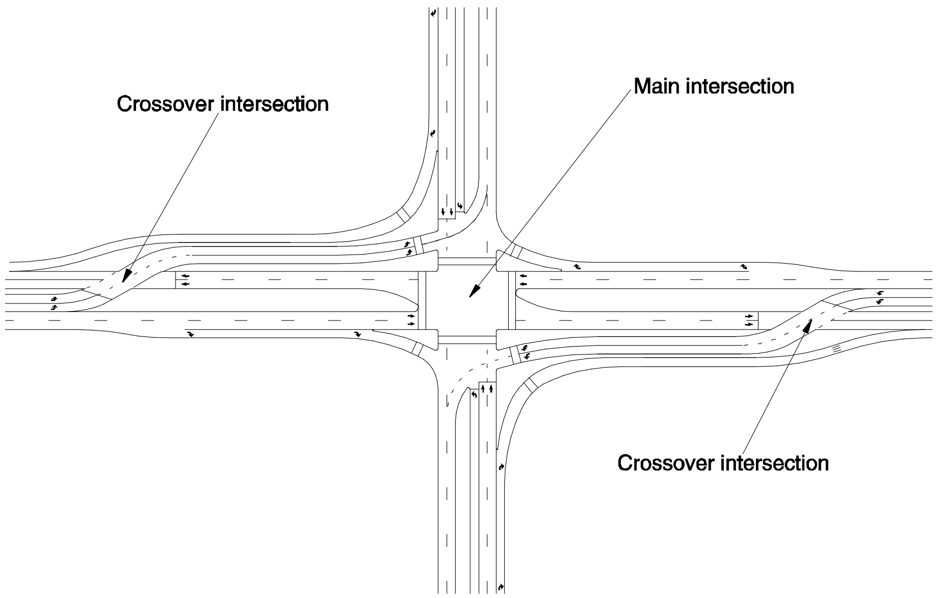


Source: FHWA *(7)*

6.7.3 Displaced Left-Turn Intersections

The Displaced Left-Turn (DLT) intersection is also known as a continuous flow intersection (CFI) and a crossover displaced left-turn intersection. The DLT intersection displaces left-turn movements of an approach to the other side of the opposing traffic flow, as shown in Exhibit 6-18. More information can be found in the *FHWA Displaced Left Turn Informational Guide (8)*.

Exhibit 6-18
Key Characteristics of a DLT Intersection

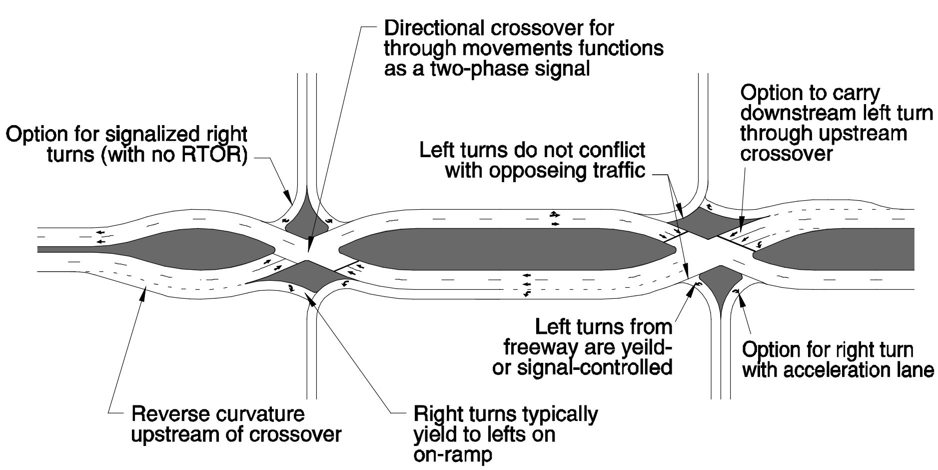


Source: FHWA *(8)*

6.7.4 Diverging Diamond Interchange

The Diverging Diamond Interchange (DDI) is also known as the double crossover diamond and is an alternative to the conventional diamond interchange. The DDI includes directional crossovers on either side of the interchange that eliminates the need for left-turning vehicles to cross the path of approaching through vehicles, as shown in Exhibit 6-19. More information can be found in the *FHWA Diverging Diamond Interchange Informational Guide (9)*.

Exhibit 6-19
Key Characteristics of a DDI



Source: FHWA *(9)*.

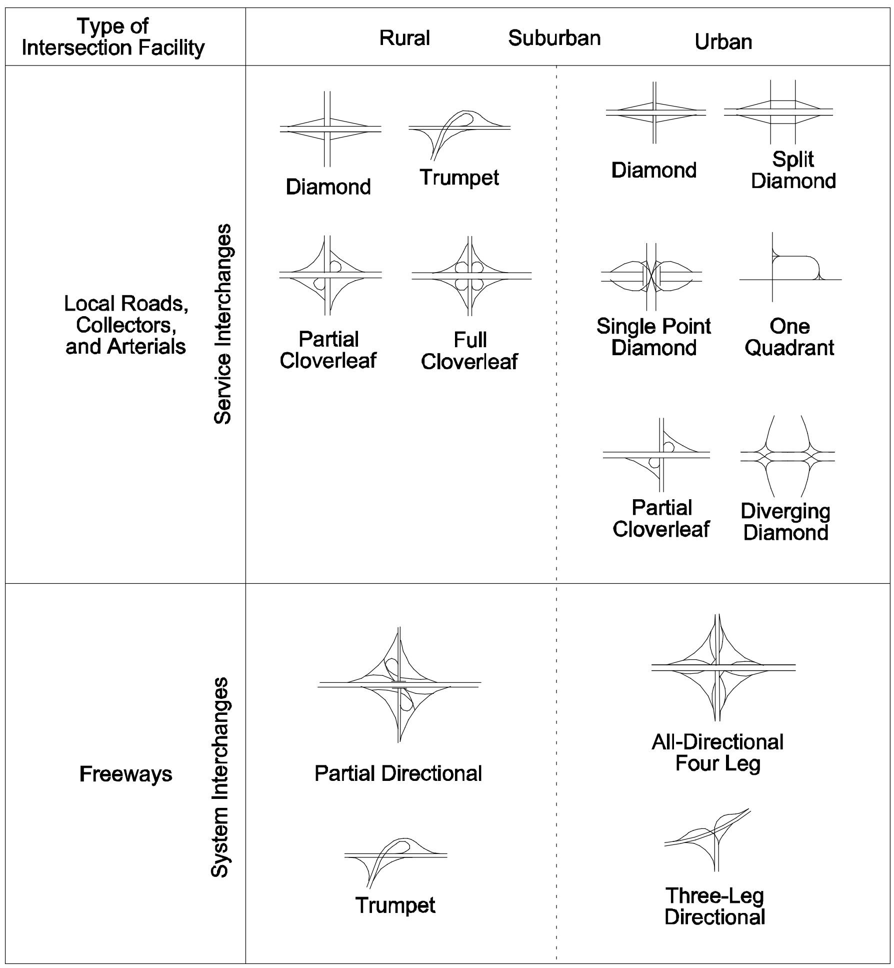
6.8 INTERCHANGES

An interchange is a system of ramps in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways on different elevation levels. The operational efficiency, capacity, safety and cost of the highway facility are largely dependent upon its design. Coordinate with the Traffic and Safety Bureau for guidance in the design of interchanges including access guidelines, selection, operations, spacing, freeway/ramp terminals, ramps, and ramp/crossroad terminals.

6.8.1 Types

There are a wide variety of interchange configurations, and Figure 6-20 shows several basic configurations of interchanges. These interchange configurations may be modified based on operational and safety needs for the specific project location.

Exhibit 6-20
Interchange Configurations



Source: AASHTO *(1)*

There are two categories of interchanges: service interchanges and system interchanges. Service interchanges are interchanges that connect a freeway to lesser facilities (e.g., local, collector, or arterial street), and system interchanges are interchanges that connect two or more freeways. Interchange configurations can be adapted to meet the needs of each category, land use, and project context. Exhibit 6-20 depicts interchanges that are adaptable on freeways as related to classifications of intersecting facilities in rural and urban environments.

In selecting the type of interchange, there are several considerations:

- Compatibility with the surrounding highway system and the functional classification of the intersecting highway,
- Route continuity and uniformity with adjacent interchanges,
- Operational characteristics,
- Road-user impacts,
- Driver expectancy,
- Topography,
- Geometric design,
- Construction and maintenance costs,
- Potential for stage construction,
- Right-of-way impacts and availability,
- Environmental impacts, and
- Potential growth of surrounding area.

6.8.2 Design Principles

Interchanges are grade-separated facilities that promote the objective of efficiency, safety, and capacity by grade separating the intersecting traveled ways (e.g., high movement volumes). The design of an interchange is influenced by a variety of factors, including highway classification, character and composition of traffic, design speed, and degree of access control. The signing needs, economics, terrain, and right-of-way should also be considered to accommodate the anticipated traffic demands.

The basic components of an interchange include the freeway, the roadway facility that it crosses, the median, ramps, and auxiliary lanes. Traffic operations and safety should guide the interchange design, with consideration for topography, local context, and cost.

Ramp spacing is a unique consideration for interchanges, and should be selected based on safety and operational impacts. Additional information regarding ramp and interchange spacing can be found in *NCHRP Report 687: Guidelines for Ramp and Interchange Spacing (10)*.

The Traffic and Safety Bureau provides additional guidance on interchange design principles.

6.9 REFERENCES

1. Transportation Research Board. *Highway Capacity Manual 2010.* Transportation Research Board of the National Academies, Washington, D.C., 2010.

2. Montana Department of Transportation (MDT). *Approach Manual for Landowners and Developers.* MDT, Helena, MT, 2013.
3. United States Access Board. *Public Right-of-Way Accessibility Guidelines (PROWAG).* Website: http://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way
4. Ray, B., I. Potts, F. Hanscom, and J. McGill. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections.* Transportation Research Board of the National Academies, Washington, D.C., 2008.
5. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide, 2nd ed.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
6. Reid, J., L. Sutherland, B. Ray., and A. Daleiden. *Median U-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
7. Hummer, J., B. Ray, A. Daleiden, and P. Jenior. *Restricted Crossing U-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
8. Steyn, H., Z. Bugg, B. Ray, and A. Daleiden. *Displaced Left-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
9. Schroeder, B., C. Cunningham, B. Ray, and A. Daleiden. *Diverging Diamond Interchange Informational Guide*. FHWA, Washington, D.C., 2014.
10. Ray, B., R. Porter, J. Leisch, and J. Mason. *NCHRP Report 687: Guidelines for Ramp and Interchange Spacing*. Transportation Research Board of the National Academies, Washington, D.C., 2011.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 7

Multimodal Design Considerations

September 2016

Contents

Chapter 7

Multimodal Design Considerations

7.1 INTRODUCTION

The explicit design for all modes of travel is an integral part of a roadway project and has an impact on the safety and operational performance for various road users, as well as construction and maintenance costs. This chapter presents the basic design principles and approach for designing multimodal design elements, including pedestrian facilities, bicycle facilities, shared used paths, crossing treatments, and transit facilities. The *Montana Department of Transportation (MDT) Geometric Design Standards* provides specific cross sectional dimensions relative to a roadway's functional classification *(1)*. The design team should also coordinate with the Traffic and Safety Bureau and Planning Division to obtain an understanding of local plans, operational and safety aspects, as well as the traffic engineering design elements for signing and pavement markings associated with the multimodal design.

7.2 DESIGN PRINCIPLES AND APPROACH

Roadway facilities should be designed and operated to enable safe access for various users, including pedestrians, bicycles, motorists, and transit riders of all ages and abilities. A fundamental consideration in establishing a multimodal improvement project is an overall vision for the facility tailored toward the specific users, project context, and desired outcome. The intended function of the facility is a key aspect in the development of an overall vision for its use.

With a clear understanding of the users and intended functions of a highway or street, the design team can work toward establishing a design that best serves the vision for the facility. Overarching design principles for each mode of travel is described below.

***MDT Geometric Design Standards* provide a starting point for the design team to make a thoughtful evaluation of the project needs in consideration of the specific context.**

An enhanced crossing provides additional treatments (e.g., signing, pavement markings, beacons, signals) to make it easier for multimodal users to cross a roadway.

- **Pedestrian facilities.** Adjacent land uses and roadway conditions frequently create a need for a certain quantity or quality of pedestrian facility above the minimum. For example, people who are walking along a high-speed roadway, benefit from more separation from motorized vehicles, while people walking in a downtown environment with a higher density of land uses may need wider pedestrian facilities to accommodate a larger walking demand.
- **Bicycle facilities.** The diversity of rural and urban roadways and the diversity of people's cycling skills and comfort levels makes bicycle facility design complex. As a result, treatments often need to be tailored to individual situations. For example, if a project goal is to attract new bicycle users, then the design team should consider providing some separation from vehicular travel lanes.
- **Shared facilities.** The anticipated usage of shared facilities will likely determine the width of the facility to minimize conflicts, as well as access to recreational destinations.
- **Crossing treatment.** The existing and/or future land uses along the roadway will likely result in natural origin-destination walking paths. People who are walking typically follow the shortest path, so the design team should consider appropriate locations at regular intervals to provide enhanced crossings based on pedestrian volumes.
- **Transit facilities**. The location (upstream or downstream of intersections) and type of bus stop (in-lane or pullout) used along a corridor are key transit design elements. The design team should coordinate with and incorporate recommendations from the MDT transit policy and local transit entity to establish desired design elements early in the project.

The criteria provided in the *MDT Geometric Design Standards* are a starting point for the design team to make a thoughtful evaluation of the project needs in consideration of the specific context. In addition, a performance-based design approach can help document the decision-making process and help the design team understand the trade-offs.

7.3 PEDESTRIANS

This section provides design guidance for pedestrian facilities and their integration into the roadway design. Additional design considerations and details for pedestrian facilities may be found in the *American Association of State Highway and Transportation Official (AASHTO) Guide for the Planning, Design, and Operation of Pedestrian Facilities (2).*

7.3.1 Conflict Areas

A pedestrian/vehicle conflict point exists anywhere a pedestrian path crosses a vehicular path, such as where a pedestrian walking path crosses vehicular travel lanes and the pedestrian is exposed for the entire duration when crossing a roadway. Exhibit 7-1 illustrates a typical intersection and highlights the pedestrian/vehicle conflict points.

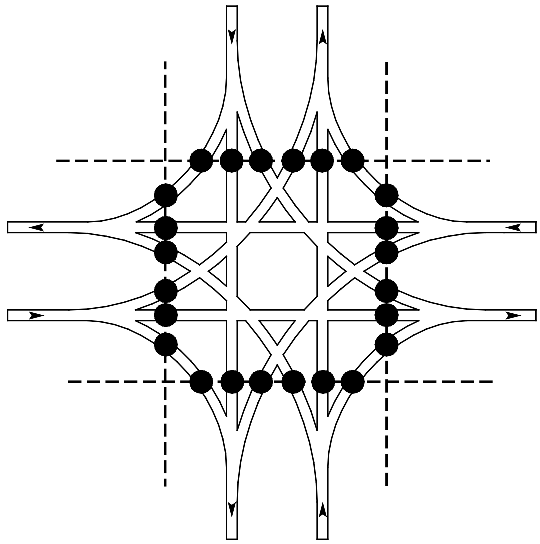


Exhibit 7-1
Diagram of Pedestrian / Vehicle Conflict Points

Typical conflict areas include the following:

- **Approaches (driveways).** Drivers need appropriate sight distance to be aware of a potential conflict with a pedestrian while entering and/or exiting an approach. This conflict area can be emphasized by providing pavement markings as well as properly maintaining appropriate landscaping in the vicinity of the approach. Treatments added to emphasize the conflict area should be considered on a case-by-case basis and may not be appropriate for all projects.
- **Intersections.** To properly design an intersection, a design team should understand the factors a pedestrian must consider when crossing at an intersection. The Traffic and Safety Bureau will design the configuration of the intersection and coordinate with the design team to locate crosswalks through the intersection.
  - A signalized intersection provides an indication when to cross a roadway. However, there may be a permissive signal phase that allows vehicular left- and/or right-turns that may conflict with pedestrians in a crosswalk.
  - Pedestrians need an unobstructed sight triangle at an unsignalized intersection to determine an appropriate time to cross.
  - The combination of roadway width and intersection corner radii sets the crossing distance at an intersection. Smaller corner radii can shorten the crosswalk, but the ability to do this depends on the design vehicle for the intersection and how vehicles are allowed to complete their turns. For example, a larger radius (or combination of radii, as discussed in Chapter 6) is typically provided at higher order facilities (e.g., arterials) to accommodate larger trucks who are expected to maintain lane position when turning right.

The objective is to design an intersection that provides sight distance for the various users to be aware of each other's presence, especially at conflict areas.

The objective is to design an intersection that provides sight distance for the various users to be aware of each other's presence, especially at these conflict areas. Section 2.8 provides the details for evaluating intersection sight distance.

7.3.2 Accessibility Considerations

A pedestrian is defined as any person traveling by foot and any mobility-impaired person using a wheelchair.

Pedestrian facilities shall be designed to be accessible to all users, regardless of ability. The United States Access Board provides many additional resources on accessibility and specific requirements for Accessible Public Rights of Way. Accessibility relates to special consideration given to pedestrians with disabilities including accommodating pedestrians with vision or mobility impairments. The design team should be familiar with the policies related to the Americans with Disability Act (ADA) and *Public Rights-of-Way Accessibility Guidelines (PROWAG) (3).*

Pedestrians may benefit from targeted outreach and additional informational material created with pedestrians in mind.

In the context of the public right-of-way, the basic principles for accessible design can be divided into the pedestrian walkway and the pedestrian crossing location. The following considerations apply:

- Provide a walkway free of obstructions and delineate the walkway through landscaping, curbing, or fencing to assist with wayfinding for visually impaired pedestrians.
- Provide sufficient space (length and width) and recommended slope rates (transverse and longitudinal) for wheelchair users and other non-motorized users such as people pushing strollers and walking bicycles.
- Construct ADA compliant pedestrian ramps with an appropriate landing with flat slopes and sufficient size at crossing points.
- Provide detectable warning devices at the end of the walkway where it intersects the street.
- Align the walkway access point with the street crosswalk, if it is marked. If the crossing is not marked, align the walkway access point to the intended crossing direction. If the crosswalk is marked, the minimum crosswalk width is 8 feet.

A wheelchair is a mobility aid and designed for and used by individuals with mobility impairments.

- Provide a sufficiently wide crosswalk through the intersection to permit pedestrians, including two wheelchair users, to pass without delay from opposing directions, and provide sufficient storage in sufficiently wide medians to allow all non-motorized users to safely wait when two-stage crossings are desired or required. Crosswalks should be designed to have a cross slope of 2-percent or less. However, the design team should consider a cross slope of 1.5-percent to allow for potential deviations and flexibility during construction.

All people—but especially those with vision, mobility, or cognitive impairments—may benefit from targeted outreach and additional informational material created to illustrate the best and safest way to cross the public roadway and use the pedestrian facilities.

7.3.3 Pedestrian Treatments

The following sections provide an overview of various pedestrian treatments that provide different levels of separation. The design team should consider the level of separation that appeals to a wide variety of users based on the project context and future vision of the facility.

7.3.3.1 Separated Pedestrian Path

A pedestrian path is a hard-surface path adjacent to the roadway in lieu of a sidewalk in areas where other bicycle facilities exist or where bicyclists typically share the road on a low-volume facility, as shown in Exhibit 7-2. Similar to a sidewalk, pedestrian paths are narrower in width and generally do not invite bicycle travel.

Exhibit 7-2
Separated Pedestrian Path

Typical applications are:

- In constrained rural areas where sidewalks are not present and shared use paths cannot be accommodated.
- As an interim treatment in urbanizing areas to make connections between sidewalk facilities.

Design considerations are:

- Typically a minimum width of 6 feet (8 feet preferred) asphalt surface.
- Pedestrian paths are typically separated from the roadway by a gravel or vegetated buffer instead of a curb and gutter.
- Though not intended for bicyclists, pedestrian paths will attract bicyclists if a separate bicycle facility is not provided.

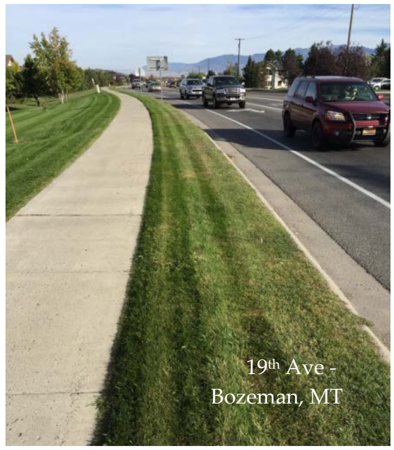
7.3.3.2 Sidewalks

A sidewalk is a dedicated pedestrian facility adjacent to the roadway and separated from vehicular traffic by a curb (e.g., curb-tight sidewalk) and buffer area (detached sidewalk), as shown in Exhibit 7-3 and Exhibit 7-4. The following guidance will help determine the need for sidewalks:

Exhibit 7-3
Curb-tight Sidewalk

1. **Sidewalks Currently Exist (Roadway or Bridge).** Where sidewalks currently exist along a roadway, the sidewalk will normally be replaced. If a bridge with an existing sidewalk is replaced or rehabilitated, the sidewalk will normally be replaced.

Exhibit 7-4
Detached Sidewalk



2. **Sidewalks Currently Do Not Exist (Roadway).** The need for sidewalks will be determined on a case-by-case basis in cooperation with the local community. In general, the design team should consider providing sidewalks along any roadway where people normally walk or would be expected to walk if they had a sidewalk available (a latent demand exists). In addition, sidewalks may be required at specific sites even if they are not needed along the entire length of the roadway. These include points of community development (schools, local businesses, shopping centers) resulting in pedestrian concentrations along the roadway. If curb and gutter is included in the roadway section, the need for sidewalks should be evaluated. This evaluation is especially critical in developing transitional areas between rural and urban areas. Where new curb and gutter sections are being proposed without sidewalks, the design team should consider adding a berm behind the curb that is wide enough to accommodate a future sidewalk.

3. **Bridge without Sidewalk/Roadway with Sidewalk**. If a bridge without a sidewalk will be replaced or rehabilitated, and if existing sidewalks approach the bridge, a sidewalk will normally be included in the bridge project. Even if not currently on the approaching roadway, sidewalks may still be necessary on the bridge if the approach roadway is a candidate for future sidewalks.

   As a more general statement of MDT policy, bridge projects within urban areas will have a sidewalk where pedestrians are legally allowed, unless there is a compelling reason not to provide a sidewalk. In addition, bridges at interchanges near urban areas should normally include sidewalks to accommodate the commercial development that may occur in the immediate vicinity of interchanges.

4. **Sidewalks Currently Do Not Exist (Underpasses).** If an underpass is within the limits of a project that includes sidewalks, then sidewalks will normally be provided through the underpass, unless this would involve unreasonable costs to modify the bridge substructure.

   For new and reconstruction underpass projects, the bridge substructure should allow space for future sidewalks through the underpass based on the eventual need for sidewalks on the roadway.

5. **One Side vs. Two Sides**. Sidewalk requirements for each side of the roadway or bridge will be evaluated individually; placing a sidewalk on each side will be based on the specific characteristics of that side.

6. **Approval**. For all projects in urban areas, the addition of sidewalk should be documented and approved in the Scope of Work Report. This applies to the roadways, bridges, and underpasses.

Design considerations are:

- Typically 6 feet or wider depending on the project context. Sidewalks should be constructed at least 5 feet wide, with a minimum of 4 feet of clear width, excluding any obstructions (e.g., utility poles).
- A buffer area between the roadway and the sidewalk is preferable in urban areas, particularly in residential areas and in locations with higher traffic speeds and volumes. This area also may be used for snow storage during maintenance activities.
- Wider sidewalks of 12 to 20 feet can be beneficial in commercial or "town center" areas to accommodate higher pedestrian volumes, street furniture, pedestrian scale lighting, business signage, bicycle parking, transit stops, and other amenities.

7.4 BICYCLES

This section provides design guidance for bicycle facilities and their integration into the roadway design. Additional design considerations and details for bicycle facilities may be found in the AASHTO *Guide for the Development of Bicycle Facilities, 4th Edition (4).*

7.4.1 Bicycle Lane Design at Intersections

Bicyclists may use different paths riding through an intersection, depending on their skill and comfort riding with motorized vehicle traffic. There are several locations that need to be addressed when planning and designing for bicycles at an intersection. These options are in addition to traveling through the intersection as a pedestrian, which may be preferable for some people.

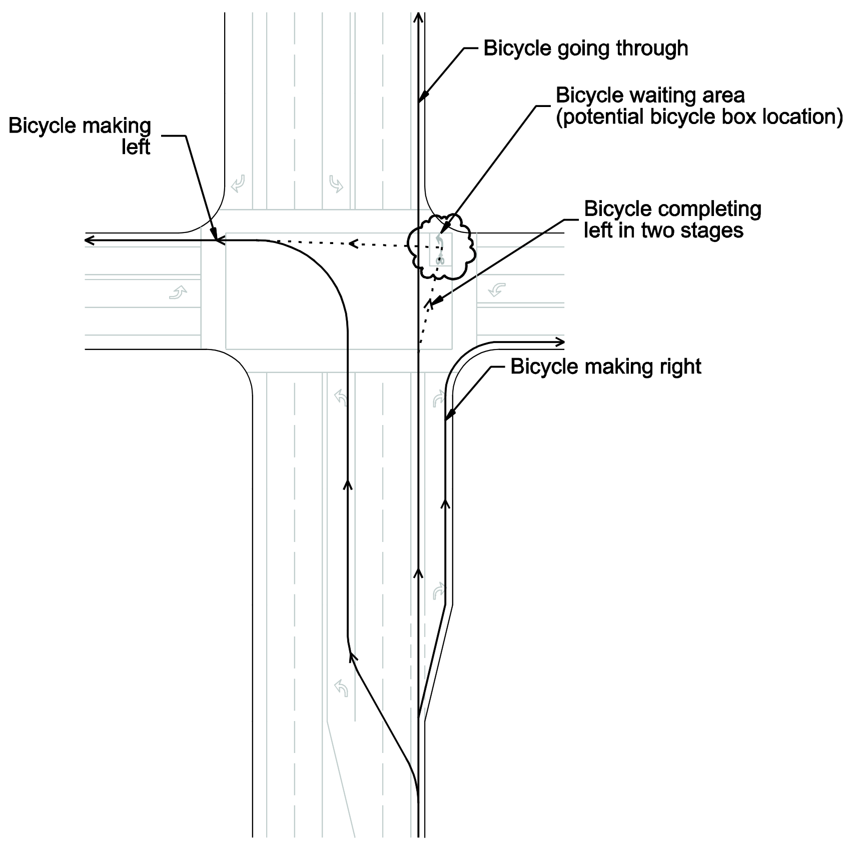
- **Through movement.** There are two common conditions for which a bicyclist needs to navigate through an intersection: a shared through/right lane with a bicycle lane on the outside, and a separate right-turn lane on the outside of the bicycle lane.
    - For the shared through/right lane condition, both the bicyclist making a through movement and the right-turning vehicle should be aware of the potential conflict.
    - When a separate right-turn is present, a bicyclist may have to ride between two streams of vehicles along the length of the right-turn lane. The entrance to the right-turn lane also presents a bicycle-vehicle conflict point.

  There may be a need to emphasize the areas where bicyclists are exposed at these conflict areas by delineating the bicycle travel areas through the intersections.
- **Right turn.** For the shared through/right lane condition, bicyclists will follow the bicycle lane and turn right onto the side street. If a right-turn lane is present, right-turning motorized vehicles and bicycles typically share the right-turn lane and, depending on their respective volumes and travel speeds, bicyclists may choose to use the sidewalk.

- **Left turn.** There are two ways for a bicycle to complete a left-turn at an intersection:
  - o Weaving across one or more traffic lanes to use the left-turn lane, as a motorized vehicle would do. This may present a challenge especially in high-volume high-speed conditions.
  - o If the intersection geometry provides a refuge area in the far-side corner, a bicycle box can be placed to allow a two-stage left turn by bicyclists. Sometimes there is no defined bicycle box, but bicyclists still complete the left turn in two stages by waiting in the far-side intersection corner.

Exhibits 7-5 and 7-6 show the range of bicyclist paths through the intersections and highlight the conflict areas and the opportunities that the design team needs to address in the design.

Exhibit 7-5
Bicycle Path



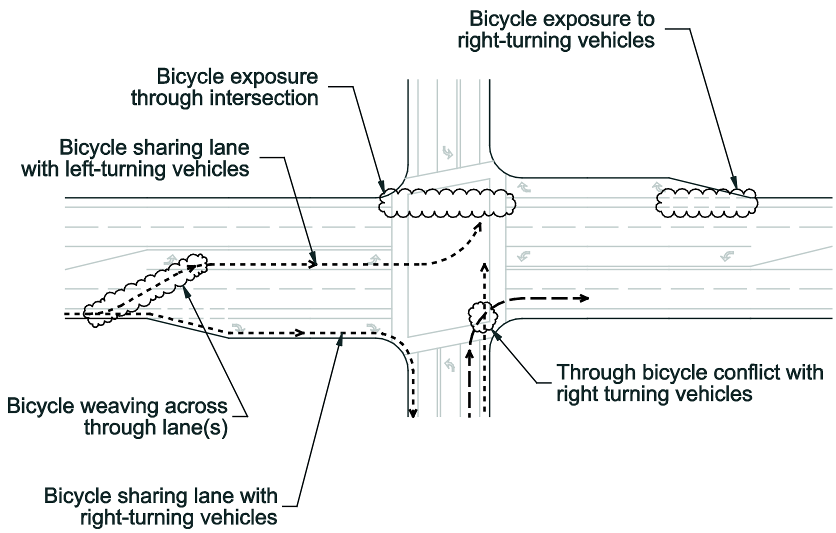


Exhibit 7-6
Bicycle Conflict Areas

7.4.2 Bicycle Treatments

The following sections provide an overview of bicycle treatments that provide different levels of separation. The design team should consider the level of separation that will appeal to a wide variety of users based on the project context, consistency with local plans and future vision of the facility. For example, bicycle treatments are commonly categorized by the level of separation they provide bicyclists from motorized vehicles. Separated facilities have been found to attract more bicyclists of a variety of ages and abilities and are generally considered "lower stress" facilities. However, separated facilities must be carefully designed to allow for safe crossings and turning movements for both motorized vehicles and bicyclists at intersections.

7.4.2.1 Paved Shoulder

A paved road shoulder can serve as space for bicycles that is separated from motorized vehicle traffic in rural areas, as shown in Exhibit 7-7.

Typical applications are:

- Typically applied on rural roadways.

Design considerations are:

- Rumble strips or pavement markings can be used to enhance safety and minimize motorists encroaching on the shoulder. The design team should verify the use of rumble strips based on the most recent policy, which is further discussed in Chapter 5.

Exhibit 7-7
Paved Shoulder

If the road is designated as a bicycle route, then consider bicycle lane treatments as described in future sections.

7.4.2.2 Standard Bicycle Lane

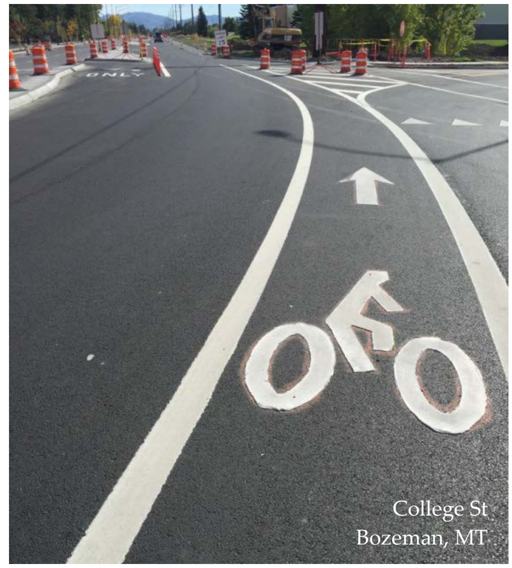


Exhibit 7-8
One-Way Separated Bicycle Lane

A standard bicycle lane is an on-street facility that provides space designated for bicyclists, separated from vehicles by pavement markings, as shown in Exhibit 7-8.

Typical applications are:

- Streets without sufficient right-of-way or pavement width for buffered bicycle lanes or separated bicycle lanes (SBLs).

Design considerations are:

- Typical bicycle lane width is 6 feet, with 5 feet in constrained locations. A minimum 4-foot width can be used on constrained segments where on-street parking is not present.
- Colored pavement can add visibility and awareness in “conflict areas” or intersections where bicycle and vehicle travel paths cross.

7.4.2.3 Buffered Bicycle Lane

Exhibit 7-9
Buffered Bicycle Lane

Buffered bicycle lanes are on-street lanes that include an additional striped buffer, typically 2 to 3 feet wide, between the bicycle lane and the motorized vehicle travel lane (as shown in Exhibit 7-9) and/or between the bicycle lane and the motorized vehicle parking lane.

Typical applications are:

- Long-distance links within and between communities.
- Streets with sufficient pavement width to provide a buffer.
- Widely applicable in both urban and rural settings.
- Segments of the bicycle network with moderate vehicle speeds or volumes.

Design considerations are:

- Typical buffer width is 2 to 3 feet, in addition to the standard bicycle lane width of 5 to 6 feet.
- Colored pavement can add visibility and awareness in “conflict areas” or intersections where bicycle and motorized vehicle travel paths cross.
- Buffer space can have diagonal stripes and/or rumble strips to discourage motorized vehicles from traveling or parking in the space.

7.4.2.4 One-Way Separated Bicycle Lane (Cycle Track)

A one-way separated bicycle lane (SBL), also known as a cycle track or protected bicycle lane, is a bicycle facility within the street right-of-way separated from motorized vehicle traffic by a buffer and/or a physical barrier. Exhibit 7-10 shows on-street parking as a buffer for the bicycle treatment. On two-way streets, a one-way SBL would be found on each side of the street, similar to a standard bicycle lane.

Exhibit 7-10
One-Way Separated Bicycle Lane

Colored pavement is not effective at adding visibility and awareness during snow and ice conditions.

Typical applications are:

- Roadway segments with sufficient right-of-way or where a motorized vehicle lane reduction (also referred to as a "road diet") can be implemented.
- Key segments of the bicycle network where more protection is desirable, such as areas with higher traffic volumes or speeds, or routes to common destinations, such as schools.
- Roadways with infrequent approaches (driveways) and side street accesses.

Design considerations are:

- Intersections must be designed to ensure visibility of bicyclists using the facility. Treatments may include high visibility pavement markings.
- Buffer type can vary depending on context, presence of parking, and available right-of-way (e.g., planters, flexible posts, parked cars, or a mountable curb).
- Colored pavement can add visibility and awareness in "conflict areas" or intersections where bicycle and motorized vehicle travel paths cross.
- Refer to the Federal Highway Administration (FHWA) *Separated Bike Lane Planning and Design Guide* for further design considerations (5).

7.4.2.5 Two-Way Separated Bicycle Lane (Cycle Track)

A two-way separated bicycle lane (SBL), also known as a two-way cycle track or two-way protected bicycle lane, is a facility within the street right-of-way separated from motorized vehicle traffic by a buffer and a physical barrier, as shown in Exhibit 7-11. Two-way SBLs serve bi-directional bicycle travel within the facility on one side of the street.

Exhibit 7-11
Two-Way Separated Bicycle Lane

Typical applications are:

- On-street connections between off-street shared use paths.

- Roadways with infrequent approaches (driveways) and side street accesses.
- Key segments of the bicycle network where more protection is desirable, such as areas with higher traffic volumes or speeds, or routes to common destinations, like schools.
- On one-way streets where two-way bicycle travel is desirable.

Design considerations are:

- Intersections must be designed to ensure visibility of bicyclists using the facility. Treatments may include high visibility pavement markings.
- Buffer type can vary depending on context, presence of parking, and available right-of-way (e.g., planters, flexible posts, parked cars, or a mountable curb).
- Colored pavement can add visibility and awareness in "conflict areas" or intersections where bicycle and vehicle travel paths cross.
- Refer to the *Federal Highway Administration (FHWA) Separated Bike Lane Planning and Design Guide* for further design considerations *(5)*.

7.4.3 Bicycle Intersection Treatments

7.4.3.1 Pavement Markings Through Intersections

Exhibit 7-12
Pavement Markings Through Intersections


Higgins Ave
Missoula, MT

Pavement markings can be extended through the intersection for both cycle tracks and bicycle lanes, as shown in Exhibit 7-12. Colored pavement can be used in "conflict zones" where vehicles and bicycles may cross paths in intersections, at approaches (driveways), or at right turn lanes.

Typical applications are:

- Intersections and conflict zones, especially in high-volume and/or high-speed areas.

Design considerations are:

- Consider white extension pavement markings to extend a treatment through an intersection or across a conflict zone. Dashed pavement markings can enhance awareness and visibility.

7.4.3.2 Two-Stage Left-Turn Box

Two-stage left-turn boxes allow bicyclists to safely and comfortably make left-turns at multilane intersections from a right-side bicycle lane or cycle track, as shown in Exhibit 7-13. Bicyclists arriving on a green light travel into the intersection and pull out into the two-stage turn queue box away from through-moving bicycles and in front of cross street traffic, where they can wait to proceed through on the next green signal phase.

Exhibit 7-13
Two-Stage Left-Turn Box

Typical applications are:

- At signalized intersections with multilane roadways, and
- At locations where a low-stress left-turn movement for bicyclists is desirable.

Design considerations are:

- Two-stage left-turn boxes should be located out of the way of through bicyclists, usually between the bicycle lane and the crosswalk. If there is on-street parking, space may be available between the bicycle lane and vehicle travel lane.
- Consider using passive bicycle detection in the two-stage left turn box to actuate the green signal phase for bicyclists.

7.4.3.3 Bicycle Boxes

Bicycle boxes are designated spaces at signalized intersections, placed between a set-back stop line and the crosswalk, that allow bicyclists to queue in front of motorized vehicles at traffic signals, as shown in Exhibit 7-14.

Exhibit 7-14
Bicycle Box

The main purpose of a bicycle box is to prevent collisions between bicyclists and right-turning motorists. Bicyclists are more visible to motorists when waiting in a bicycle box because they are in front of them rather than beside them.

Typical applications are:

- Signalized intersections with high bicycle volumes, and
- Signalized intersections where a designated bicycle route turns left.

Design considerations are:

- Minimum depth of the bicycle box should be 10 feet, and it should extend across the bicycle lane, any buffer space, and at least one adjacent vehicle travel lane.

7.5 SHARED USE PATHS

Exhibit 7-15
Shared Use Paths

Shared use paths are paved, bi-directional, trails away from roadways that can serve both pedestrians and bicyclists, as shown in Exhibit 7-15. Shared use paths can be used to create longer-distance links within and between communities and provide regional connections. They play an integral role in recreation, commuting, and accessibility due to their appeal to users of all ages and skill levels. Additional design considerations and details for bicycle facilities may be found in the AASHTO *Guide for the Development of Bicycle Facilities, 4th Edition (4).* Chapter 5, Section 5.2.9 provides additional cross section information for shared use paths.

Typical applications are:

- Medium- to long-distance links within and between communities that provide for commuter and recreational use.
- Parallel to roads in rural areas where sidewalks and on-street facilities are not present.

Design considerations are:

- Shared-use paths are best suited in areas where roadway crossings can be minimized (such as parallel to travel barriers such as uninterrupted roadways, railroad tracks, rivers, shorelines, and natural areas).
- Crossings may need high-visibility treatments.
- A width of 10 feet is recommended for low-pedestrian/bicycle-traffic contexts; 12 feet or wider should be considered in areas with moderate to high levels of bicycle and pedestrian traffic. An 8-foot width may be acceptable in constrained settings.
- The minimum recommended separation between the roadway and the shared use path is 5 feet.
- The maximum cross slope on a shared use path is 2 percent.
- Pavement markings can be used to indicate distinct space for pedestrian and bicycle travel.

Design cross slope for 1.5 percent to allow for potential deviations and flexibility during construction. The AASHTO Green Book recommends a 1 percent cross slope, as discussed in Chapter 5, Section 5.2.9.2.

7.6 CROSSING TREATMENT

The design team should coordinate with the Traffic and Safety Bureau to identify and understand the operational review and study completed to determine the appropriate treatment. This coordination should provide documentation to support the treatment decision, regarding the type and location of treatment. In addition, documentation will provide an overview of the various treatments considered.

7.6.1 Crossing Evaluation Considerations

The design team should coordinate with the Traffic and Safety Bureau to identify the appropriate crossing treatment. *NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings*, supplemented with research on the rectangular rapid flashing beacon (RRFB), provides guidance on improving pedestrian safety at unsignalized crossings *(6)*. The RRFB is a pedestrian-actuated set of amber light-emitting diodes (LEDs) that rapidly flash when actuated. The NCHRP report provides tools for developing appropriate crossing treatments based on vehicle speeds, traffic volumes, and anticipated number of pedestrian and bicycle crossings.

Coordinate with the Traffic and Safety Bureau to identify the appropriate crossing treatment.

Potential crossing treatments may include any of the following, or in some cases a combination of two or more of these: pavement markings, signing, flashing beacons, RRFBs, pedestrian hybrid beacons (PHBs), raised crosswalks and fully signalized crossings that are coordinated with the main intersection. Speech messages for visually impaired pedestrians may be considered for signalized type crossings.

7.6.2 Enhanced Crossing Treatments

Enhanced crossing treatments provide different levels of improvements for multimodal users. The design team should consider treatments that appeal to a wide variety of users based on the project context and future vision of the facility. For example, treatments for pedestrian mid-block crossings range from a high-level of enhancement, such as a grade-separated crossing structure, to a lower level of enhancement, such as the warning offered with a high-visibility crosswalk. Intermediary levels of enhancement can be provided with a pedestrian hybrid beacon or rectangular rapid flashing beacon. The design team should coordinate with the Traffic and Safety Bureau to determine the need for an operational study to identify the appropriate type of treatment. The design team should incorporate the results from the study.

7.6.2.1 High Visibility Crosswalk

High visibility crosswalks consist of reflective pavement markings and accompanying signage at intersections and priority crossing locations, as shown in Exhibit 7-16. The location of the crosswalk is coordinated with the Traffic and Safety Bureau.

**Exhibit 7-16
High Visibility Crosswalk**

Coordinate with the Traffic and Safety Bureau for the appropriate crosswalk striping and signing to be installed at crosswalks.

Typical applications are:

- At intersections of arterials, collectors, and/or other facilities with moderate to high pedestrian/bicycle usage, vehicle volumes and speeds.
- At midblock locations, especially in conjunction with other treatments.
- At designated school crossings.

Design considerations are:

- Crosswalk pavement markings may vary (e.g., continental)
- Crosswalks should have a minimum width of 8 feet, but wider crossings are preferred in areas with a high number of pedestrians.

7.6.2.2 Raised Pedestrian Crossing

Exhibit 7-17
Raised Pedestrian Crossing

Raised pedestrian crossings are typically provided on lower order facilities (e.g., local roads or collectors).

Raised pedestrian crossings bring the level of the roadway up so that it is even with the level of the sidewalk. The objective is to provide a level pedestrian crossing path and require vehicles to slow down to pass over the pedestrian crossing, as shown in Exhibit 7-17. Raised pedestrian crossings can be used at midblock crosswalks or intersections.

Typical applications are:

- At midblock crossings where speed control is desired.
- At intersections where low-volume streets intersect with high-volume streets or where a roadway changes character (such as from commercial to residential).
- Generally not on transit routes for passenger comfort.

Design considerations are:

- Raised crosswalks should be at the same level as the sidewalk and at least as wide as the sidewalk or pedestrian path that approaches the intersection. In some cases, the level of the sidewalk is sloped downward and the elevation of the roadway sloped upward to join at a midway point.
- Detectable warning devices are needed for pedestrians where they leave the sidewalk and enter the crossing area.
- Provide appropriate treatments for drainage needs.
- Maintenance activities should be considered, particularly for roadways that are generally plowed during snow conditions.

7.6.2.3 Bulb-Out/Curb Extensions

Exhibit 7-18
Bulb-Out/Curb Extension

These include an extension of the curb or the sidewalk into the street (in the form of a bulb), usually at an intersection, that narrows the vehicle path, inhibits fast turns, and shortens the intersection crossing distance for pedestrians, as shown in Exhibit 7-18.

Typical applications are:

- Midblock or intersection pedestrian crossings on streets with unrestricted on-street parking.

Design considerations are:

- The curb extensions need accessible curb ramps and detectible warnings.
- Landscaping on the curb extension differentiates the path for pedestrian travel, especially for pedestrians with vision impairments.
- Appropriate space should be provided to accommodate design vehicles identified for the specific roadway.
- Drainage should be maintained along gutter pan or designed with added elements to change the drainage pattern.

Bulb-outs may create unique drainage concerns for the design team to address.

7.6.2.4 Crossing Island (Pedestrian Refuge)

A crossing island in the median provides an area in the middle of the road for pedestrians to stop if needed when crossing the road in two stages (i.e., crossing one direction of vehicular travel at a time), as shown in Exhibit 7-19. Also called pedestrian refuge islands or median refuges, they can be used at intersections or midblock crossings. Exhibit 7-20 shows a crossing island for an intersection with a channelized right-turn lane.

Exhibit 7-19
Crossing Island

Exhibit 7-20
Crossing Island with Channelization

Typical applications are:

- Potential treatment for crossings of multilane roadways.
- Often used in areas with high levels of vulnerable pedestrian users, such as near schools or senior centers/housing.
- Often applied in areas with high traffic volumes.

It is not always feasible to provide a desirable median width for pedestrian refuge; a narrow median with a cut-through may be used as a speed management technique.

Design considerations are:

- Crossing islands must have at least 6 feet of raised median width (measured face-to-face)
- They can be applied in conjunction with other traffic control treatments.

7.6.2.5 *Rectangular Rapid Flashing Beacon (RRFB)*

**Exhibit 7-21
Rectangular Rapid Flashing Beacon**

These crossing treatments include signs that have a pedestrian-activated "strobe-light" flashing pattern to attract motorists' attention and provide awareness of pedestrians and/or bicyclists that are intending to cross the roadway, as shown in Exhibit 7-21.

Typical applications are:

- Midblock crossings or shared use paths with medium to high pedestrian or bicycle demand and/or medium to high traffic volumes.

Design considerations are:

- The push button to activate the RRFB should be compliant with the *Manual on Uniform Traffic Control Devices (MUTCD)* and easily accessible by pedestrians, including wheelchair users *(7)*.
- A push button in the median island (if present) can help pedestrians when crossing multilane facilities.

7.6.2.6 *Pedestrian Hybrid Beacon*

**Exhibit 7-22
Pedestrian Hybrid Beacon**

Coordinate with the Traffic and Safety Bureau to identify the appropriate treatment location.

A pedestrian hybrid beacon is a pedestrian/bicyclist activated signal that rests in dark when not in use, as shown in Exhibit 7-22. It begins with a yellow light flashing that turns solid to alert drivers to slow, and then displays a solid red light requiring drivers to remain stopped while pedestrians and bicyclists receive a walk indication. Finally, the beacon changes to alternating flashing red lights while pedestrians and bicyclists receive a flashing don't walk indication to signal that motorists may proceed after pedestrians and bicyclists are no longer in conflict.

Typical applications are:

- Midblock crossings with high pedestrian or bicycle demand.
- At locations where shared use paths intersect the mainline roadways, where appropriate.
- At multilane roundabout entries and exits.

Design considerations are:

- The push button to activate the pedestrian hybrid beacon should be compliant with the *Manual on Uniform Traffic Control Devices (MUTCD)* and easily accessible by pedestrians, including wheelchair users *(7)*.

7.6.2.7 Pedestrian Signal

Exhibit 7-23
Pedestrian Signal

This crossing type can provide pedestrians with a signal-controlled crossing where pedestrian volumes warrant full signalization, as shown in Exhibit 7-23. The signal remains green for the mainline traffic movement until actuated. Pedestrian signals are typically applied at intersections that were previously stop controlled and pedestrian/bicycle volumes warrant a signal. The push button to activate the pedestrian signal should be compliant with the *Manual on Uniform Traffic Control Devices (MUTCD)* and easily accessible by pedestrians, including wheelchair users *(7)*. Refer to ADA and *PROWAG* for additional guidance *(3)*.

7.6.2.8 Grade Separated Crossing

Exhibit 7-24
Grade Separated Crossing - Overpass

A grade-separated crossing is a bridge (overpass/underpass) or a tunnel (underpass) that carries non-motorized traffic over or under a motorized corridor or other barrier to travel, as shown in Exhibit 7-24 and Exhibit 7-25.

Typical applications are:

- Crossings of limited access freeways, multilane roadways, or railroads.
- Shared use path crossings may have grade-separated crossings to provide comfortable and safe crossings for users of all skills and levels.

Exhibit 7-25
Grade Separated Crossing - Underpass

Design considerations are:

- If a substantial slope or out-of-direction travel is required, some bicyclists or pedestrians may avoid using the crossing; therefore, consider minimizing slope and out-of-direction travel, if possible.
- In selecting a grade separated crossing, consider the surrounding topography and natural features.
- Consider sight distance for bicyclists entering the facility to see oncoming bicyclists or pedestrians. If not possible, consider providing a stop controlled traffic device.
- If the crossing is used by pedestrians, it must be accessible to all users and meet ADA requirements.

7.7 TRANSIT

Exhibit 7-26
Transit Stop

The design team needs to work collaboratively with transit and local agencies to incorporate transit design (e.g., bus stop locations) into transportation improvement projects when appropriate. In addition, the design team should refer to MDT transit policy for guidance. Transit stops are inherently associated with people walking to and from the stop, so the same principles that apply to pedestrian crossings also apply to transit stops. An example of a transit stop is shown in Exhibit 7-26.

There are a few additional principles to consider for bus stops:

- **Bus position relative to lane.** There are two options: stopping in the travel lane or using a bus pullout.
    - Stopping in the lane will impact traffic operations (e.g., delay in through traffic), and will also influence bicycle travel when a bus stops in the bicycle lane when present. However, stopping in the lane is easier for bus drivers to resume travel after stopping.
    - A bus pullout allows traffic to continue while the bus is stopped. However, bus drivers sometimes have a challenge (e.g., finding a gap) entering the travel lane from the bus pullout. If right-of-way is available, a bus pullout will be required. If right-of-way is not feasible to acquire, in-lane bus stops may be considered.

Coordinate with the Traffic and Safety Bureau to determine if a feasibility study is needed to identify appropriate locations for bus stops at an intersection.

- **Location at intersection.** Buses typically stop either near-side or far-side at an intersection. Sometimes buses will use an upstream (near-side) location in a right-turn lane to pull out of traffic without building a separate bus pullout. The location depends on the overall signal operations along the corridor and may include the following:
    - Transit signal priority
    - Queue jump opportunities

Coordinate with the Traffic and Safety Bureau to determine if a feasibility study is needed to consider transit signal priority and/or queue jump opportunities.

- **Midblock location.** A bus stop at a midblock location may be desired due to a destination that attracts high transit usage along a road segment. When midblock stops are used, signal control such as a RRFB, a pedestrian hybrid beacon, or a traditional midblock signalized crossing should be considered. Buses typically stop beyond the crossing to allow pedestrians to cross behind the bus where they are more visible to oncoming traffic.

The overall goal is to design a system that provides facilities (e.g., bus stops) in a consistent manner to meet user expectancy.

7.8 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards*. MDT, Helena, MT, 2016.
2. AASHTO. *Guide for the Planning, Design, and Operation of Pedestrian Facilities*. AASHTO, Washington, D.C., 2004.
3. United States Access Board. Public Right-of-Way Accessibility Guidelines (PROWAG). Website: http://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way
4. AASHTO. *Guide for the Development of Bicycle Facilities, 4th Edition*. AASHTO, Washington, D.C., 2012.
5. FHWA. *Separated Bike Lane Planning and Design Guide*. FHWA, Washington, D.C., 2015.
6. Fitzpatrick, K., et. al., *TCRP 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings*. Transportation Research Board of the National Academies, Washington, D.C., 2006.
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MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 8

Urban Design Considerations

September 2016

Contents

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Chapter 8

Urban Design Considerations

8.1 INTRODUCTION

Chapter 8 is intended to provide design guidance for urban facilities including local streets, collectors and arterials. The design approach described in this chapter considers various transportation modes and addresses how to integrate motorized vehicles, pedestrians, and bicycles into the urban environment in an effective manner. This chapter will:

- Refer to the tools and multimodal design considerations described in Chapter 7,
- Provide additional information on urban intersections to expand on Chapter 6,
- Apply the basic roadway design principles documented in Chapters 3 (Horizontal Alignment), 4 (Vertical Alignment), and 5 (Cross Section Elements), and
- Introduce drainage topics that are further discussed in Chapter 11 (Drainage and Irrigation Design).

MDT urban design standards are presented in the *MDT Geometric Design Standards*, which are referenced throughout this chapter *(1).*

8.2 DESIGN PRINCIPLES AND APPROACH

The urban design environment is faced with a variety of design considerations that are typically not found in a rural area. Intersections are often spaced relatively close together, are designed to accommodate various modes, and a wide range of traffic speeds and volumes. Therefore, the horizontal and vertical alignment must be designed to appropriately accommodate these intersections and modes. Additional challenges that are often encountered in an urban design environment include *(2)*:

- Limited right-of-way for cross section elements;
- Constrained horizontal and vertical alignments;

- Limited sight distance;
- Offset intersection alignments;
- Multiple driveway approaches to access adjacent properties;
- Increased presence of pedestrians, bicycles, and transit;
- Accommodation of utilities;
- Reduced speeds in specific areas (i.e., traffic calming); and
- Local policies, plans and ordinances.

Design of urban streets typically consists of either designing a new facility, where new right-of-way can be acquired to accommodate the desired cross section elements, capacity, and modes; or upgrading an existing facility to improve safety, provide more capacity, integrate various modes, or meet other project objectives. In either design approach, the following factors should be considered *(2)*:

- Right-of-way acquisition procedures and needs;
- Permanent traffic control;
- Public involvement;
- Multidisciplinary coordination;
- Pedestrian, bicycle, transit, and motorized vehicle needs;
- Utility relocation and potential conflicts;
- Adjacent access, including building access;
- Drainage design;
- Guidance for consistent cross sections;
- Location and design of medians;
- Street lighting;
- Cross section trade-offs, such as the widths associated with travel lanes, turn lanes, on-street parking, and bicycle lanes;
- On-street parking;
- Design vehicles; and
- Landscaping.

8.3 PROJECT CONTEXT

Understanding the project context, purpose of the facility, and target facility users for a project is critical to making appropriate design decisions within an urban design environment. As described in the *MDT Context Sensitive Solutions Guide (CSS Guide)*, a successful CSS project seeks to understand the landscape, the community, valued resources, and the role of all appropriate modes of transportation in each unique context before developing engineering solutions *(3)*. This also includes public involvement that is tailored to the community and project needs to help guide design decisions, and occurs early and frequently throughout the project. The approach outlined in the *CSS Guide* is consistent with applying a performance-based design approach (Chapter 1, Section 1.2.2), which can also provide a framework for initiating projects in urban areas.

Urban design environments may be particularly constrained due to adjacent land use and are often faced with balancing the needs of motorized vehicles, pedestrians, bicycles, and transit. The design team should be prepared to apply criteria for differing types of design features as a roadway transitions through various types of land uses that often exist along corridors in urban settings.

Urban design projects on existing roads are sometimes triggered by adjacent redevelopment and may require the design to provide street frontage improvements. The majority of the major transportation improvement projects are developed through capital improvement programs consistent with long-range transportation plans.

Understanding the primary purpose of the facility and targeted users can help guide the design decisions and priorities for balancing the needs of each user. Urban arterials may have higher traffic volumes and focus on mobility for vehicles, as well as providing facilities for pedestrians, bicycles, and transit. In these cases, access to adjacent properties may be somewhat limited, using medians, and separate turn lanes. However, for urban facilities such as collectors or local streets, the design may focus on providing access to businesses, neighborhoods, or other land uses, for all types of users. In some cases, the roadway may be specifically designed for pedestrian, bicycle, and transit facilities, and design decisions may enhance facilities to encourage these types of users.

Designing roadway improvements for an existing urban roadway can be complex, particularly if right-of-way acquisition is not feasibly possible in highly developed areas. Design decisions may be impacted by coordination with utilities (water, sewer, storm water, electric, gas, and communication lines), potential for on-street parking, and multimodal facilities. Balancing the project needs and target users for the facilities in a constrained environment may result in design values that do not meet the *MDT Geometric Design Standards.* In these cases, a design exception will be required, which allows the design team to document each design decision with the justification for the proposed design value and provide clear explanation of how the design may result in a better fit for the project context and target users.

A performance-based design approach, as described in Chapter 1, provides a clear framework for evaluating design decisions and documenting each decision.

8.4 APPLYING GEOMETRIC DESIGN IN URBAN ENVIRONMENTS

Designing in an urban context does not imply that the design team should not meet design values and criteria. Rather, the design team should apply the basic geometric design principles in an urban setting considering and evaluating trade-offs between design, safety, and operations. This section highlights key concepts the design team should consider when refining improvements within the urban environment.

The *MDT Geometric Design Standards* for urban roadways reflect flexibility for cross sectional dimensions and provide a great starting point.

8.4.1 **Urban Cross Sections**

The design team should use the *MDT Geometric Design Standards* to determine the cross sections for urban roadways *(1)*. Exhibit 8-1 illustrates an example of an urban cross section at an intersection.

Exhibit 8-1
Urban Cross Section at an Intersection

College Street
Bozeman, MT

In addition, cross sections in urban environments may include the following design features:

1. **Narrow Cross Section**. Due to right-of-way constraints, travel lanes in urban roadways may be narrower than in rural roadways. There are numerous factors related to lane width that influence operations and safety.

2. **Bicycle Facilities.** Bicycle facilities should be considered for roadway designs in urban environments, particularly in corridors with high motor vehicle volumes and on roadways where bicycle facilities are consistent with local plans. Bicycle facilities can have varying levels of separation and/or protection from motor vehicle traffic, ranging from separated cycle tracks, with the most separation from motor vehicles, to shared roadways, with no separation. Exhibit 8-2 illustrates an urban cross section with bicycle facilities. Additional information on bicycle facilities can be found in Chapter 7, Section 7.4.

   Exhibit 8-2
   Urban Cross Section with Bicycle Facilities

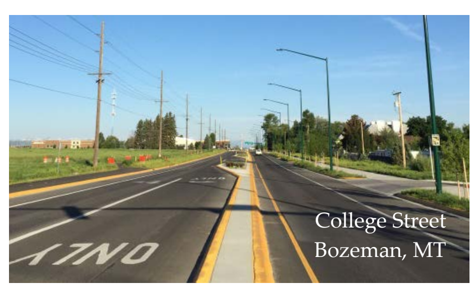
   Pedestrian Facilities. When pedestrian facilities are provided along roadways, buffered facilities are typically preferred. Intersections and driveway approaches introduce conflict areas between pedestrians and other modes. Appropriate pedestrian facility design should provide high visibility of pedestrians in these conflict areas. Chapter 7, Section 7.3 and Chapter 5, Section 5.2.9 provide additional cross sectional information on pedestrian facilities.

3. **Integrating Landscape Features.** Urban environments have opportunities to incorporate landscape features within the roadway design, particularly if there is a buffer area separating the pedestrian access route and the roadway, landscaped medians, and stormwater management areas such as detention ponds. Exhibit 8-3 illustrates an urban cross section with a landscaped median and Exhibit 8-4 illustrates a raised median. These landscape features may include grass, low vegetation, planting areas, rock, mulch, and street trees. These features may also be used as a stormwater management tool,

   Exhibit 8-4
   Urban Cross Section with a Landscaped Median

   Exhibit 8-3
   Urban Cross Section with a Raised Median

as described in Section 8.5. Adequate roadside clearance should be maintained for landscape features integrated into the design. Chapter 9, Section 9.2 provides additional information on roadside clearance.

Exhibit 8-5
On-Street Parking in a Downtown Setting

Exhibit 8-6
Parking with a Bicycle Facility

4. **Parking.** On-street parking is a consideration in urban environments, particularly in commercial areas with multiple businesses along a corridor. Exhibit 8-5 illustrates parking in a downtown setting and Exhibit 8-6 illustrates parking with a bicycle facility. There are several types of parking designs, such as parallel parking and angled parking (both forward-in and back-in). There are trade-offs with each design, in terms of the footprint, the number of spaces that can be accommodated, the potential safety impacts, and ease of use by drivers. Parking designs should also consider the interaction between parking maneuvers and bicycles. Parking spaces should be designed with consideration of the specific need and local context of each facility. In areas with potential for loading, parking lanes may be designed to be wider to accommodate these maneuvers.

5. **Crown/Cross Slope.** Urban roadways typically have a crown cross section with the crown at the center of the road with drainage to the outside. A crown that is offset from the center of the road may be used to avoid impacts along the corridor or to match an existing roadway cross section that differs in elevation from one side to the other. In addition to an offset crown, different cross slopes on each side of the crown point may be used. The drainage design should reflect the new flow patterns as a result of this offset crown. Pavement preservation projects should consider the impact of various methods of paving (e.g., overlay, mill-and-fill). An overlay will likely result in a steeper cross slope in the bicycle lane, parking, or shoulder area, which can impact user comfort and pedestrian crossing slopes.

8.4.2 Intersection Design

Intersection design in urban environments should consider the following design elements:

Exhibit 8-7
Example of a Design Vehicle

The Traffic and Safety Bureau is responsible for the overall intersection design, including accommodating design vehicles and traffic signal design.

1. **Design vehicles.** Urban intersections may be used by vehicles that are unique to the urban environment, such as delivery trucks or fire trucks. Exhibit 8-7 illustrates a Streamline Transit Bus. The design team should identify the design vehicle and a design approach for:
   - accommodating the design vehicle within the intersection area (pavement between curbs without encroaching into opposing lanes); or
   - designing for the vehicle to stay within specific lanes.

   The intersections should be designed for these vehicles to operate safely and efficiently.
2. **Various modes**. Intersections are a meeting point for multiple users of the roadway, particularly in urban environments. As such, they are potential conflict locations due to the various movements and modes. The right-of-way allocation for the various modes and movements must be clear to all users to minimize confusion and improve efficient operations and safety at the intersection.
3. **Adjacent approach access.** Commercial areas in urban environments are likely to have approach accesses near intersections, such as driveways to various retail land uses. The locations of the approach accesses must be determined in considering the proximity of the intersection and ensuring that it does not adversely impact the operations or safety of the intersection. Approach access may be limited if it is found to be too close to the intersection. Additional information on approach access is provided in the *MDT Approach Manual for Landowners and Developers*, located at the following link on the MDT Website.

   MDT Approach Manual for Landowners and Developers

8.4.3 Horizontal and Vertical Alignments

There are unique design characteristics that may be considered in an urban area. The design team should have a clear understanding of the urban roadway type, project context, and existing constraints to make appropriate design decisions. Horizontal and vertical alignment design in urban environments may consider the following design features:

1. **Driver Expectations**. Due to the complexities of designing within urban environments, the resulting roadways may not be what roadway users are accustomed to navigating. Roadways should be designed in such a

way that they meet driver expectations and establish consistency along the facility and/or within the transportation system.

2. **Horizontal Alignment.** Typically, circular curves will be used on roadways in urban conditions. In urban areas, it is acceptable to use compound curves to avoid obstructions, minimize right-of-way impacts and match existing topography. MDT has adopted the use of a maximum rate of superelevation (e_{max}) of 4 percent for the selection of minimum curve radius and superelevation rates for urban design. Typically, the axis of rotation is about the centerline of traveled way, but unique circumstances such as turn lanes and offset crowns may require a shift in the axis of rotation. Deflection angles of 1 degree or less without horizontal curvature may be appropriate for urban streets. At intersections, higher deflection angles may be acceptable depending on design speed, traffic volumes, and type of traffic control. Offsets through an intersection should be evaluated on a case-by-case and MDT may consider a transition across the intersection no greater than 6 feet (less preferred) based on the context.
3. **Vertical Alignment.** Developing profile grade lines in urban areas often is more challenging due to limited right-of-way, closely spaced intersections, the need to meet existing roadside development, and accommodating drainage on curbed streets. Long vertical curves and grades on urban streets are generally impractical because in most cases the profile grade line must allow the roadway cross section to match existing conditions. No minimum vertical curves lengths are provided for urban streets. Vertical curves are not required when the algebraic difference in grades is less than 1.0 percent. When practical, the vertical point of intersection (VPI) should be located at intersections. Fairly flat approach grades should be provided at intersections to accommodate vehicles pulling away from a stopped position and to provide accessible cross slopes at pedestrian crossings. Using K-values to determine if vertical curves meet minimum stopping sight distance (SSD) may not be reliable, because curve lengths are typically shorter than the minimum SSD in urban conditions. Therefore, curves should be checked graphically to determine if they meet minimum SSD requirements.

Chapter 7, Section 7.3.2 provides additional information on accessibility considerations.

8.4.4 **Traffic Calming**

There are areas within an urban environment in which lower speeds are more appropriate, such as collectors and local roads. To encourage lower speeds in these areas, vertical and horizontal traffic calming measures may be implemented as part of the roadway design.

- Vertical traffic calming measures may include: speed humps, speed tables, and/or raised intersections.
- Horizontal traffic calming measures may include curb extensions, mini roundabouts, and/or chicanes.

Additional information on traffic calming measures can be found on the ITE website on traffic calming measures (4), which is provided on the MDT website at the following link:

ITE Traffic Calming Measures

8.5 DRAINAGE DESIGN

Drainage design in urban environments has the following considerations.

Exhibit 8-8
Drainage example

1. **Low points.** All low points in curbed sections should have drainage inlets. Exhibit 8-8 illustrates a drainage example. Additional drainage inlets may be required between low points to keep drainage spread widths from encroaching into travel lanes. When feasible, the roadway should be designed to drain water away from pedestrian crossings. Where this is not possible, drainage inlets should be installed just upstream of pedestrian ramps.
2. **Crown.** When the roadway crown is offset to match roadside improvements or avoid conflicts, it may change drainage patterns by placing additional drainage on one side of the roadway. In such cases, the appropriate drainage features should be in place to handle the additional drainage. Existing drainage feature capacities should be checked to ensure sufficiency or to determine if an improvement is required.
3. **Drainage Inlets.** Drainage inlets should not be located in designated bicycle lanes, whenever possible and covers should have a bicycle-friendly design.
4. **Flat Grades.** When reconstructing a curbed roadway with existing drainage challenges caused by very flat grades, the new roadway grade line may need to be raised (rolled) between drainage inlets to provide sufficient flow line grades at the curb. In some cases, such as areas where the curb and adjacent sidewalk must match multiple existing building accesses, a separate curb grade may be used to roll the grade quickly between closely spaced drainage inlets.
5. **Stormwater**. Landscaping in urban environments provides opportunities for stormwater management. Drainage mechanisms can be incorporated in the roadway cross sections by using buffer areas and/or bioswales.

8.6 BALANCING TRADE-OFFS AND OBJECTIVES

Urban design projects often present unique challenges for making decisions within a constrained environment with multimodal needs, varying land use, and existing utilities. To make appropriate design decisions that meet the project objectives and serve the target users of the facility, the design team should have a clear understanding of the trade-offs of each decision. This includes balancing the project objectives for the design, operations, and safety of the facility. The design team should coordinate closely with the Traffic and Safety Bureau to understand the operational and safety trade-offs for each design decision.

Two key techniques to use in balancing competing objectives and understanding the trade-offs are (a) context-sensitive design, and (b) flexibility in design practices. While the two are related and complementary, they bring different aspects to the design process.

Local officials may have knowledge of approved plans and an understanding of the overall project "vision" that can help start a project off in the right direction.

8.6.1 **Context-Sensitive Design**

Context-sensitive design is a key aspect of designing in an urban environment to produce a successful project. One of the most effective methods to achieve successful projects in an urban setting is to engage the public and local officials early and often throughout the design project. In an urban environment, stakeholders are often adjacent to and familiar with the project and can easily see the impacts of each design improvement and the decisions associated with the project. Public involvement can help identify the needs of users and provide insight on the project constraints and overall objectives. Building relationships with the public during the project process and getting these insights can help the design team understand the trade-offs and make decisions that align with the public's priorities.

An effective public engagement process that results in community-based solutions typically reflects the following key elements:

- Identify a group of key stakeholders who are most directly affected by the project and represent a range of diverse interests. These can include, but are not limited to, residents, business owners, leaders of community organizations, transportation providers, elected officials, and affected public agencies. Key stakeholders are most effective if they are engaged throughout the project, they bring their perspective to the project but are also willing to listen and adapt to others' opinions, and they are willing to be a champion for the project in representing it to others.
- Provide the various stakeholders, local officials and general public a basic understanding of the components and implementation tools of a project.
- Integrate several educational sessions into the meetings and public workshops so that the stakeholders and general public gain a better understanding of the geometric, safety, operational, and environmental constraints and opportunities associated with a project.
- Engage the stakeholders and general public to develop formal concepts in a workshop environment. This approach makes them part of the

solution rather than merely commenting on concepts developed by others.

- Continue with public involvement throughout the project to keep the public informed and ensure that the design meets the original intent of project. It is particularly valuable to be able to demonstrate responsiveness to public input.

The *MDT CSS Guide* provides additional information on conducting a CSS Process that includes effective public involvement to achieve the project purpose *(3)*.

8.6.2 **Flexibility in Design Practices**

The guidelines in this RDM are intended to provide the design team with a set of preferred practices that will suffice the majority of the time, with the flexibility to use good engineering judgment where needed to deviate from these practices in a thoughtful and appropriate way. A context-sensitive design, as discussed in the previous section, may require flexibility around design values. When considering flexibility around the preferred practices, it is the responsibility of the design team and the engineer-in-responsible-charge to answer each of the following questions:

- Why does this specific value exist? Are there documented safety, operational, or other reasons for the value being what it is?
- What are the trade-offs associated with a variance from this value? Quantify these trade-offs wherever possible using evaluation tools.

A performance-based design approach integrated into the road design project development process enables design team to make informed decisions about the performance trade-offs. This is especially helpful when developing solutions in fiscally and physically constrained environments. Examples of performance-based tools that can be used as a resource for conducting a project with this approach are described in Chapter 1.

The MDT design exception process is intended to be the primary method for documenting design decisions where variations from *MDT Geometric Design Standards* are being proposed. These design decisions are not simply cases of not being able to meet design values; rather they represent an opportunity for the design team to use good engineering judgment to make the best decisions for a particular project. Additional information on design exceptions is available in Chapter 2, Section 2.9.

8.7 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.
2. Institute of Transportation Engineers (ITE). *Urban Street Geometric Design Handbook.* ITE, Washington, D.C., 2008.
3. MDT. *MDT Context Sensitive Solutions Guide*. MDT, Helena, MT, 2015.
4. ITE. Traffic Calming Measures Website: http://www.ite.org/traffic/tcdevices.asp

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 9

Roadside Safety

September 2016

Contents

Chapter 9

Roadside Safety

The ideal roadway would be free of obstructions or other hazardous conditions within the entire highway right-of-way. However, this may not be practical because of economic, environmental or drainage factors. Chapter 9 presents the design principles and guidance for roadside safety. This includes information on clear zone distances, which are designed to adequately provide a clear recovery space for the majority of drivers who run off the road. This chapter also provides criteria for the use of roadside barriers, median barriers, breakaway devices and impact attenuators where providing the clear zone is not practical.

9.1 DESIGN PRINCIPLES AND APPROACH

Each project should be evaluated for opportunities to enhance the roadside environment from a safety perspective. New construction or major reconstruction projects, where changes in horizontal and vertical alignment are possible, offer the most opportunities to provide an obstacle free clear zone or implement roadside treatments. The available funds for roadside safety treatments for existing roadways are often limited. Therefore, the objective of roadside safety is to focus on the features that may provide the most safety enhancement to the overall project while balancing the other design considerations and cost tradeoffs.

Roadside safety is a design process involving the application of a clear zone and exercising good judgment in the evaluation of potential roadside safety treatments.

The steps within this process are described below:

1. Determine clear zone based on design speed, geometric features, side slopes, and traffic volumes;
2. Identify obstacles within the clear zone;

3. Determine the best roadside treatment by eliminating, relocating, making breakaway, shielding the obstacle, or delineating (in that order); and
4. If it is decided that the obstacle should be shielded, determine type and length of barrier.

This chapter will outline the concept of roadside clear zone and provide a variety of roadside treatments and alternatives available. Roadside safety elements should be closely coordinated with other geometric design elements of the roadway. Chapters 3, 4, and 5 should be referenced to understand how the roadway horizontal and vertical alignments, as well as the cross section, may impact roadside safety elements and may help the design team understand the tradeoffs for various design decisions. The design team should continue to refer to the *MDT Geometric Design Standards* for specific criteria, particularly related to roadside slopes *(1)*. Design decisions should be documented in the Scope of Work or Plan-in-Hand Report, and documented in a design exception if MDT criteria are not met.

In addition, many of the design details for roadside safety can be found in the *MDT Detailed Drawings*, which are provided at the following link on the MDT website:

MDT Detailed Drawings

Additional information regarding roadside safety is provided in the *American Association of State and Highway Transportation Officials (AASHTO) Roadside Design Guide (2).*

9.1.1 Range of Treatments

If a roadside obstacle is within the clear zone, the design team should select the treatment that is most practical and cost-effective for the site conditions. The range of treatments, listed in order of preference, include the following:

1. Eliminate obstacles or design proposed features free of obstacles (such as slope flattening to avoid barrier warrants, removing rock outcroppings, and removing point obstacles);
2. Relocate the obstacle;
3. Where applicable, make the obstacle breakaway (such as sign posts and luminaire supports);
4. Shield the obstacle with a roadside barrier, which is also considered an obstacle and should only be used when other alternatives cannot be achieved; or
5. Delineate the obstacle.

The selected treatment will be based upon the traffic volumes, roadway geometry, proximity of the obstacle to the traveled way, project context (rural versus urban), nature of the hazard, costs for remedial action, and crash experience. The design team should evaluate roadside barrier installations early in the project design if they are a possible consideration for inclusion. A decision to do nothing may require a documented design exception.

9.1.2 Rumble Strips

Longitudinal shoulder and centerline rumble strips may be added to a roadway cross section to alert tired or inattentive drivers. Rumble strips should be installed in accordance with the *MDT Rumble Strip Policy* and in conjunction with the *MDT Detailed Drawings* and project plan details. The *MDT Rumble Strip Policy* can be found on the MDT website at the following link.

MDT Rumble Strip Guidance

9.2 ROADSIDE CLEAR ZONES

9.2.1 General Application

Engineering judgment is the evaluation of available pertinent information and the application of appropriate principles for the purpose of making design decisions.

The clear zone widths presented in the *RDM* provide guidelines for creating a clear recovery space for the majority of drivers who run off the road. Each application of the clear zone distance should be evaluated individually, and the design team should apply and document appropriate engineering judgment.

Exhibit 9-1 presents clear zone distances for design. When using the recommended distances, the design team should consider the following:

1. **Context**. If a formidable obstacle (see Section 9.3.1) lies just beyond the clear zone, it may be appropriate to remove or shield the obstacle if costs are reasonable. Conversely, the clear zone should not be achieved at all costs. Limited right-of-way or unacceptable construction costs may result in unshielded obstacles within the clear zone or may lead to the installation of a barrier. Unshielded obstacles within the clear zone, including the adjusted clear zone for horizontal curves (*CZc*), should be approved through the design exception process described further in Chapter 2, Section 2.9.
2. **Boundaries.** The design team should not use the clear zone distances as boundaries for introducing roadside obstacles such as bridge piers, non-breakaway sign supports, utility poles or landscaping features. Place these items as far from the traveled way as practical.
3. **Roadside Cross Section.** The recommended clear zone distance will be based on the type of roadside cross section. Section 9.2.2 presents several schematics for the various possibilities.
4. **Measurement.** All clear zone distances are measured from the edge of the traveled way. For auxiliary lanes that function similar to through lanes (e.g., climbing lanes and weaving lanes), the clear zone is measured from the edge of the auxiliary lane based on the mainline design speed and mainline design Annual Average Daily Traffic (AADT).
5. **Utility Occupancy Area.** It should be noted that the utility occupancy area is independent of the clear zone. It is possible for the utility occupancy area to be located inside of the clear zone. The final placement of utilities is negotiated between MDT and the utility companies. For paved roads, utilities should be located outside the clear zone, but no less than 30 feet from the edge of the outermost lane. When the final placement location of the utility has been determined, the design team should evaluate the

proposed location and determine whether a design exception should be pursued, or the utility feature should be shielded.

9.2.2 Clear Zone Design

The recommended clear zone distance from Exhibit 9-1 should be selected based on the highway design speed, geometric features, slope condition, and traffic volumes. Generally, the design team should select the clear zone distance for the steepest slope encountered when more than one slope falls within the clear zone. For clear zone traffic volumes, the Design AADT will be the total AADT of the roadway including both directions of travel, for both divided and undivided facilities. Refer to Sections 9.2.2.1 and 9.2.2.3 for clear zone adjustments on horizontal curves and in cut sections.

Exhibit 9-1 presents the criteria for clear zones on fill slopes which run parallel to the highway. Appendix K provides example calculations for clear zones.

Exhibit 9-1
Clear Zone Distances

Design Speed	Design AADT	Fill Slopes/Fore slopes		
		6:1 or Flatter	5:1	4:1
40 mph or less	< 750	8	8	10
	750-1499	10	12	14
	1500-6000	12	14	16
	> 6000	14	16	18
45 mph	< 750	10	12	14
	750-1499	14	16	18
	1500-6000	16	20	24
	> 6000	20	24	26
50 mph	< 750	12	12	14
	750-1499	16	18	20
	1500-6000	18	22	26
	> 6000	22	26	28
55 mph	< 750	12	14	18
	750-1499	16	20	24
	1500-6000	20	24	30
	> 6000	22	26	32
60 mph	< 750	16	20	24
	750-1499	20	26	32
	1500-6000	26	32	40
	> 6000	30	36	44
70 mph	< 750	20	22	26
	750-1499	24	30	36
	1500-6000	30	36	42
	> 6000	32	38	46
80 mph	< 750	24	26	30
	750-1499	28	32	38
	1500-6000	34	40	46
	> 6000	38	44	50

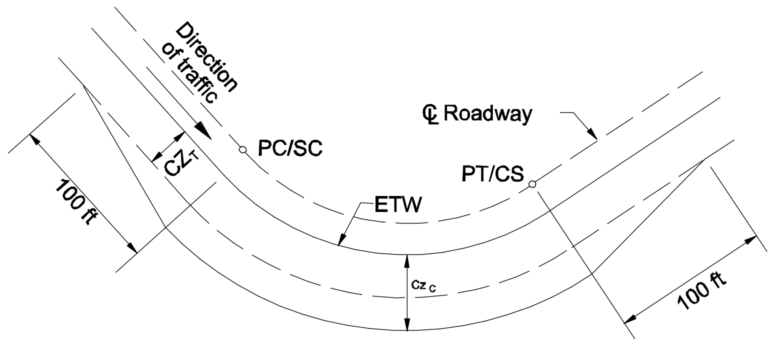
Notes:
- For 3:1 slopes, see the procedure in Section 9.2.2.2.
- All distances are measured from the edge of the traveled way (ETW).

9.2.2.1 Clear Zone Adjustment for Horizontal Curves

On the outside of horizontal curves, run-off-the-road vehicles may travel a farther distance from the traveled way before regaining control of the vehicle. The design team should modify the clear zone distance obtained from Exhibit 9-1 for horizontal curvature. The modified clear zone value for horizontal curves will be used to determine if a design exception to the clear zone criteria is necessary; see Section 9.2.2.5. This adjusted clear zone will also be the initial clear zone used if further adjustment is needed for non-recoverable slopes within recovery areas.

Exhibit 9-2 illustrates the application of the clear zone adjustment on a curve. Exhibit 9-3 provides recommended adjustments for horizontal curves.

Exhibit 9-2
Horizontal Curve Adjustments



Notes:
On the inside of horizontal curves, use the clear zone distance for a tangent roadway.
CZ_t = clear zone on tangent section
CZ_c = clear zone on horizontal curve
ETW = edge of traveled way.

Exhibit 9-3
Clear Zone Adjustment Factors for Horizontal Curves

Radius (ft)	Design Speed (mph)					
	40	**45**	**50**	**55**	**60**	**70**
2950	1.1	1.1	1.1	1.2	1.2	1.2
2300	1.1	1.1	1.2	1.2	1.2	1.3
1970	1.1	1.2	1.2	1.2	1.3	1.4
1640	1.1	1.2	1.2	1.3	1.3	1.4
1475	1.2	1.2	1.3	1.3	1.4	1.5
1315	1.2	1.2	1.3	1.3	1.4	
1150	1.2	1.2	1.3	1.4	1.5	
985	1.2	1.3	1.4	1.5	1.5	
820	1.3	1.3	1.4	1.5		
660	1.3	1.4	1.5			
495	1.4	1.5				
330	1.5					

Notes:
This table matches the *2011 Roadside Design Guide.*
1. Adjustments apply to the <u>outside</u> of a horizontal curve only.
2. Corrections are typically made only to curves less than 2950-foot radius.
3. The applicable clear zone distance on a horizontal curve is calculated by:
   $$CZ_C = (K_{CZ})(CZ_T)$$
   where: CZ_C = clear zone on outside of curve
   K_{CZ} = curve adjustment factor
   CZ_T = clear zone on a tangent section from Exhibit 9-1
4. For curves intermediate in the table, use a straight-line interpolation.
5. See Exhibit 9-2 for the application of CZ_C to the roadside around a curve.
6. Round the computed clear zone distance up to the next higher 1-foot increment.

9.2.2.2 Parallel Slopes

There are four types of fill slopes: recoverable, non-recoverable, barn-roof, and critical. The following sections discuss each type of fill slope and discuss the application of Exhibit 9-1.

1. **Recoverable Fill Slopes**. For parallel fill slopes 4:1 and flatter as shown in Exhibit 9-4a, the recommended clear zone distance can be determined directly from Exhibit 9-1.
2. **Non-Recoverable Fill Slopes.** Non-recoverable slopes are composed of traversable slopes (as defined here) and critical slopes (steeper than 3:1). For parallel fill slopes between 3:1 (inclusive) and 4:1 (exclusive) as shown in Exhibit 9-4b, adjust the clear zone to include a minimum 10-foot recovery area beyond the toe of the fill slope. It is recommended that sufficient right-of-way be acquired to ensure that the recovery area can be maintained and cleared of obstacles. The following procedure is used to determine the adjusted clear zone:

a. Ensure that the slope in the recovery area beyond the toe is 4:1 or flatter. Determine the clear zone from Exhibit 9-1 using the slope rate beyond the toe, the applicable design speed and traffic volume.

b. To determine the recovery area distance beyond the fill slope toe, subtract the width of the recoverable slope(s) between the edge of travel way and the top of non-recoverable fill slope from the distance in Step 2a.

c. If the distance in Step 2b is greater than or equal to 10 feet, this distance will be the width of the recovery area. If the distance in Step 2b is less than 10 feet, the minimum recovery area will be 10 feet beyond the toe.

d. The adjusted clear zone is the distance from the edge of the traveled way to the outside limit of the recovery area; see Exhibit 9-4b.

A barn-roof slope is a two-step sloping technique in which a less steep slope (within the clear zone) is followed by a steeper slope to minimize the right-of-way needed.

3. **Barn-Roof Fill Slope** This design requires less right-of-way and embankment material than a continuous, flatter slope, see Exhibit 9-4c. However, the use of barn-roof slopes requires a design exception to the MDT's slope criteria; see Chapter 2, Section 2.9. A barn-roof slope cannot be used just to eliminate guardrail.

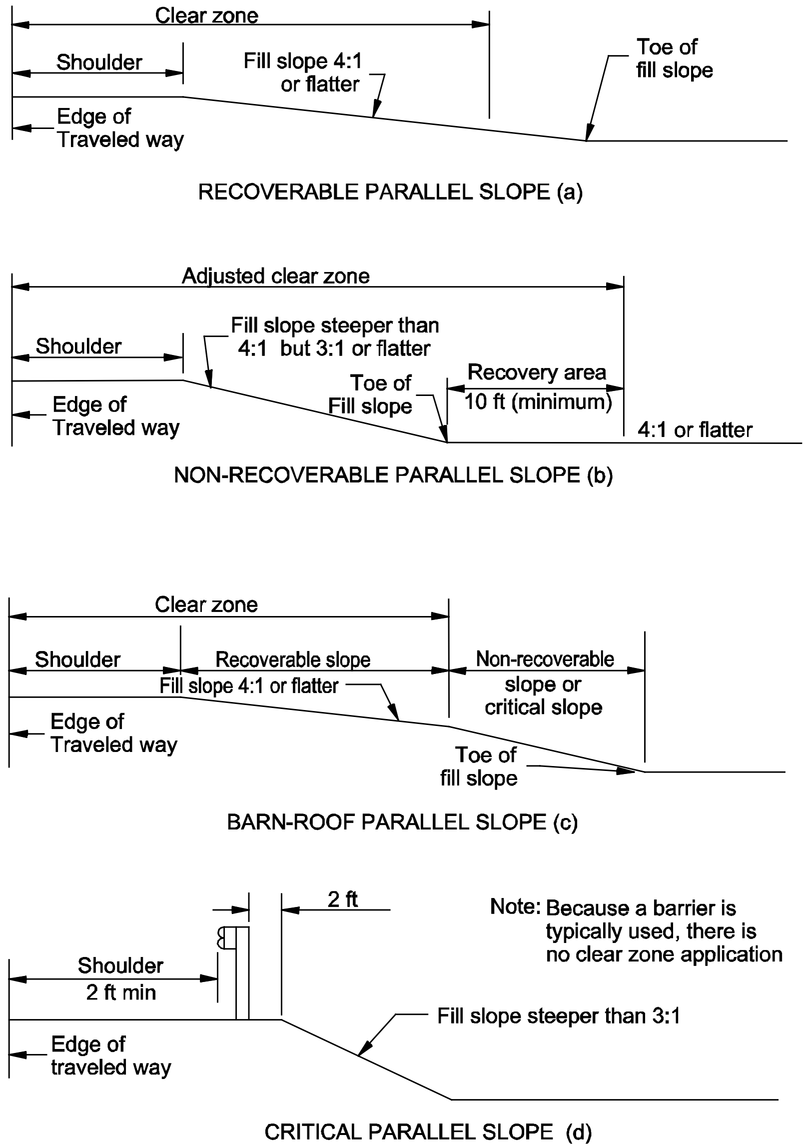
   a. Recoverable/recoverable barn-roof fill slopes may be designed with two recoverable slope rates; the second slope is steeper than the slope adjacent to the shoulder. If the clear zone for the flatter slope extends beyond the hinge point between the two slopes, determine the clear zone using the steeper slope.

   b. Recoverable/non-recoverable barn-roof fill slopes may be designed with a recoverable slope leading to a non-recoverable slope (Exhibit 9-4c). The clear zone should be provided entirely on the recoverable slope (i.e., the shoulder and recoverable slope should equal the clear zone distance). If the clear zone based on the recoverable slope extends beyond the slope break between the recoverable and non-recoverable slope, use the procedure in Step #2 (Non-Recoverable Fill Slopes) to determine the lateral extent of the clear zone.

   c. Recoverable/critical barn-roof fill slopes may be designed with a recoverable slope leading to a critical slope (i.e., fill slopes steeper than 3:1). See Exhibit 9-4c. This barn-roof design may only be used if there are no other practical alternatives. The clear zone based on the recoverable slope rate should be provided entirely on the recoverable slope (i.e., the clear zone should equal or be less than the sum of the shoulder width and recoverable slope width). Otherwise, a barrier may be warranted. See Section 9.3.2.

4. **Critical Fill Slope.** A 3:1 slope is a practical maximum when considering maintenance operations (e.g., mowing), erosion control and roadside safety. Fill slopes steeper than 3:1 are critical slopes and may require a barrier if located within the clear zone. Critical slopes should be reviewed for stability by the Geotechnical Section. See Exhibit 9-4d and Section 9.3.2.

Exhibit 9-4
Clear Zone Application for Fill Slopes



9.2.2.3 Cut Slopes

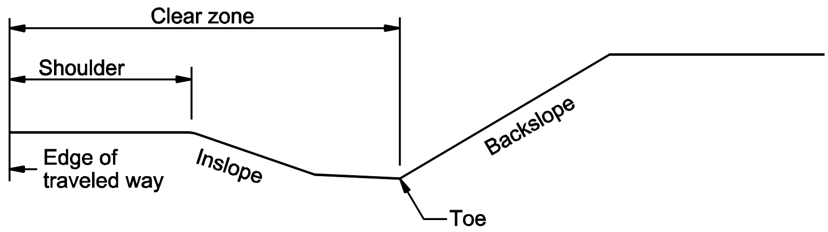
Exhibit 9-5 presents the clear zone application for ditch sections typically constructed in roadside cuts without curbs. The applicable clear zone across a ditch section will depend upon the inslope, the backslope, the horizontal location of the toe of the backslope, and various highway factors (e.g., design speed and traffic volumes). Use the following procedure to determine the recommended clear zone distance:

1. **Check Inslope.** Use Exhibit 9-1 to determine the clear zone based on the ditch inslope.
2. **Check Location of the Toe of Backslope**. Based on the distance from Step #1, determine if the toe of the backslope is within the clear zone. The toe of the

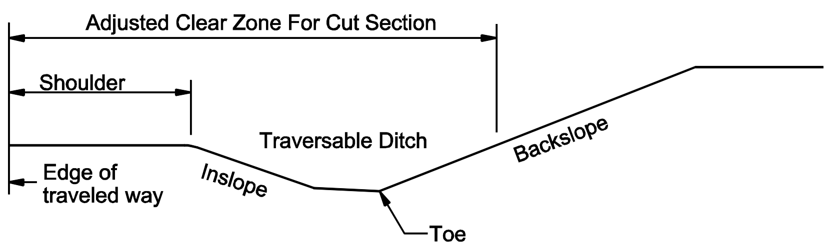
backslope is defined as the intersection of the ditch bottom and the backslope. If the toe is at or beyond the clear zone, then the design team usually need only consider roadside obstacles within the clear zone on the inslope and within the ditch. If the toe is within the clear zone, the design team should determine if the ditch is traversable.

3. **Check Ditch Traversability**. The design team should evaluate the traversability of the ditch cross section. See Section 9.3.5.1. If the ditch is not traversable, the ditch should be relocated outside the clear zone or redesigned as a traversable ditch without impact to the existing flow patterns within the project area.
4. **Clear Zone Adjustment for Cut Backslope (Earth Cuts).** If the toe of the backslope is within the clear zone distance from Step #1 above and the ditch is traversable, determine an adjusted clear zone that will extend onto the backslope. Exhibit 9-5 provides an illustration. This clear zone will be a distance beyond the toe of backslope as follows:
    a. Calculate the percentage of the clear zone available to the toe of the backslope.
    b. Subtract this percentage from 100 percent and multiply the results by the clear zone for the backslope in Exhibit 9-6, which presents the application for backslope clear zone factors.
    c. Add the available clear zone to the toe of the backslope to the value determined in Step 4b. Round the total up to the next higher 1 foot increment. This yields the required clear zone from the edge of traveled way to a point on the backslope.
5. **Clear Zones (Rock Cuts).** For rock cuts with a steep smooth backslope, the clear zone should be adjusted to the toe of the backslope and no shielding of the slope is required. The rock cut should be relatively smooth to minimize the hazards of vehicular impact. If the face of the rock is rough or rock debris occurs in the ditch section, a barrier may be warranted.

Exhibit 9-5
Clear Zone Application for Cut Slopes



TOE OF BACKSLOPE NOT WITHIN CLEAR ZONE (a)



TOE OF BACKSLOPE WITHIN CLEAR ZONE (b)

Exhibit 9-6
Adjusted Backslope Clear Zone Factors

Design Speed	Design AADT	Backslope/Earth cuts 6:1 or Flatter	5:1	4:1	3:1
40 mph or less	< 750	7	7	7	7
	750-1499	12	12	12	12
	1500-6000	14	14	14	14
	> 6000	16	16	16	16
45 mph	< 750	10	10	8	8
	750-1499	14	14	12	12
	1500-6000	16	16	14	14
	> 6000	20	20	18	16
50 mph	< 750	12	10	10	10
	750-1499	16	14	12	12
	1500-6000	18	16	14	14
	> 6000	22	20	18	16
55 mph	< 750	12	12	10	10
	750-1499	16	16	14	12
	1500-6000	20	18	16	14
	> 6000	22	22	20	18
60 mph	< 750	14	14	12	10
	750-1499	20	18	16	12
	1500-6000	24	22	18	14
	> 6000	26	26	24	20
70 mph	< 750	16	16	14	12
	750-1499	22	20	18	16
	1500-6000	28	24	22	20
	> 6000	30	30	26	24
80 mph	< 750	18	18	16	14
	750-1499	24	22	20	18
	1500-6000	30	26	24	22
	> 6000	32	32	28	26

Notes
1. To use this table, follow procedure in Section 9.2.2.3 Step 4.
2. All distances are measured from the edge of the traveled way (ETW).

9.2.2.4 Curbed Sections

The clear zone width is not reduced due to the presence of curb. However, because substantial development typically occurs in urban areas, it is usually impractical to remove or shield all obstacles within the clear zone. Use the following guidelines when curbs are encountered:

1. **Horizontal Clearance**. For roadways within the boundaries of an urban area where the design speed is less than or equal to 45 miles per hour, the recommended minimum horizontal clearance to an obstruction is 1.5 feet from the face of curb. However, if practical, provide a 5-foot to 10-foot clearance, especially at intersections and driveway entrances.
2. **Sidewalks.** Where sidewalks are adjacent to the curb, locate all appurtenances behind the sidewalk, if practical. In addition, the design team should ensure that sufficient sidewalk width is available between appurtenances and the curb to meet the Americans with Disability Act (ADA) clearance criteria; see Chapter 7 for additional information on multimodal design considerations and the MDT criteria in the *MDT Geometric Design Standards (1)*.

Refer to Chapter 2, Section 2.2.1 for detailed functional classification descriptions of rural and urban roadways.

9.2.2.5 Design Exceptions

The design team must seek a design exception when the proposed design does not provide the clear zone criteria presented in this section. Additional information on design exceptions for clear zone criteria is presented in Chapter 2, Section 2.9.

9.3 ROADSIDE BARRIER WARRANTS

9.3.1 Roadside Obstacles

Section 9.2 presents the recommended clear zone distances for various highway conditions. These distances should be free of any fixed or non-traversable obstacles. In general, barrier warrants are based on the relative severity between impacting the barrier and impacting the obstacle. Examples of roadside obstacles may include:

- Non-breakaway: sign supports, luminaire supports, traffic signals poles, railroad signal poles, and fire hydrants;
- Concrete footings extending more than 4 inches above the ground;
- Bridge piers and abutments at underpasses, bridge parapet ends, and pedestrian rail ends (see Exhibit 9-7);
- Retaining walls;
- Trees with diameter greater than 4 inches (at present or at maturity);
- Rough rock cuts;
- Large boulders;
- Critical parallel slopes;

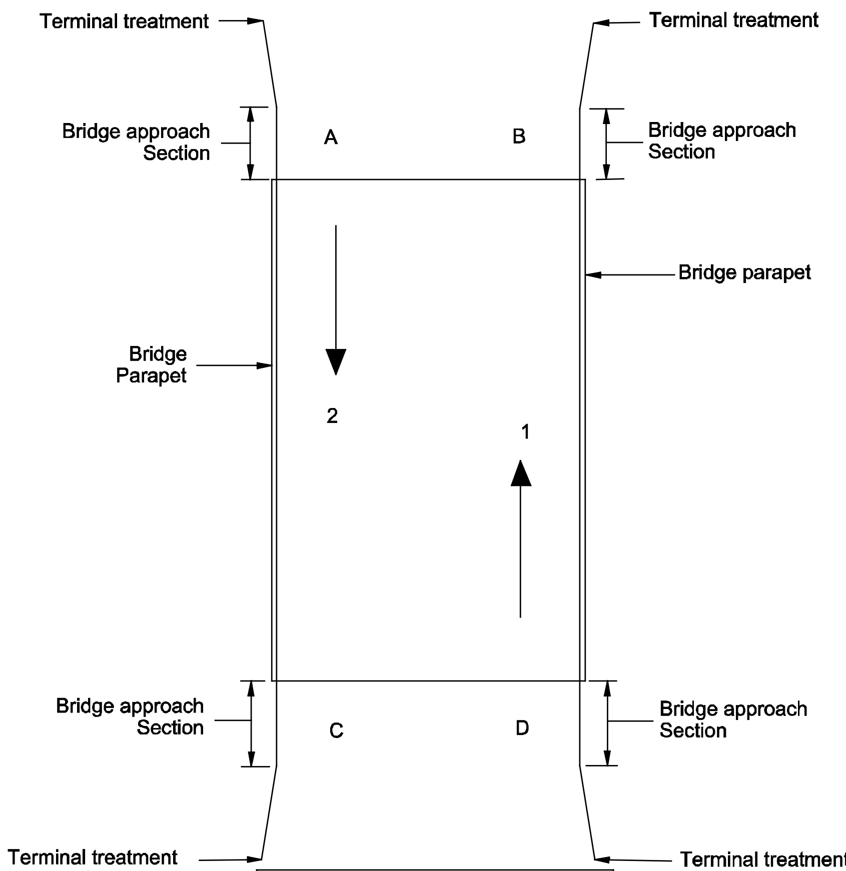
Once the design team has concluded that an obstacle is located within the clear zone, the first attempt should be to remove or relocate the obstacle or to make the object breakaway.

- Streams or permanent bodies of water (where the depth of water is at least 12 inches);
- Non-traversable ditches;
- Utility poles or towers; and
- Culvert headwalls and ends.

If it is not practical to remove or relocate the obstacle, a barrier should be installed only if engineering judgment indicates it is a reasonable solution. For example, it would probably not be practical to install a barrier to shield an isolated point obstacle, such as a tree, located near the edge of the clear zone.

Shielding obstacles located just outside the clear zone may be appropriate particularly for features or sites that have a crash history, or if there is a potential for harm if encountered by an errant vehicle. For example, shielding a bridge end location just outside the clear zone may be justified, due to the potential severity of the crash and running speeds higher than the design speeds. These situations should be reviewed and addressed during the development of the project.

Exhibit 9-7
Barrier Warrants at Bridges



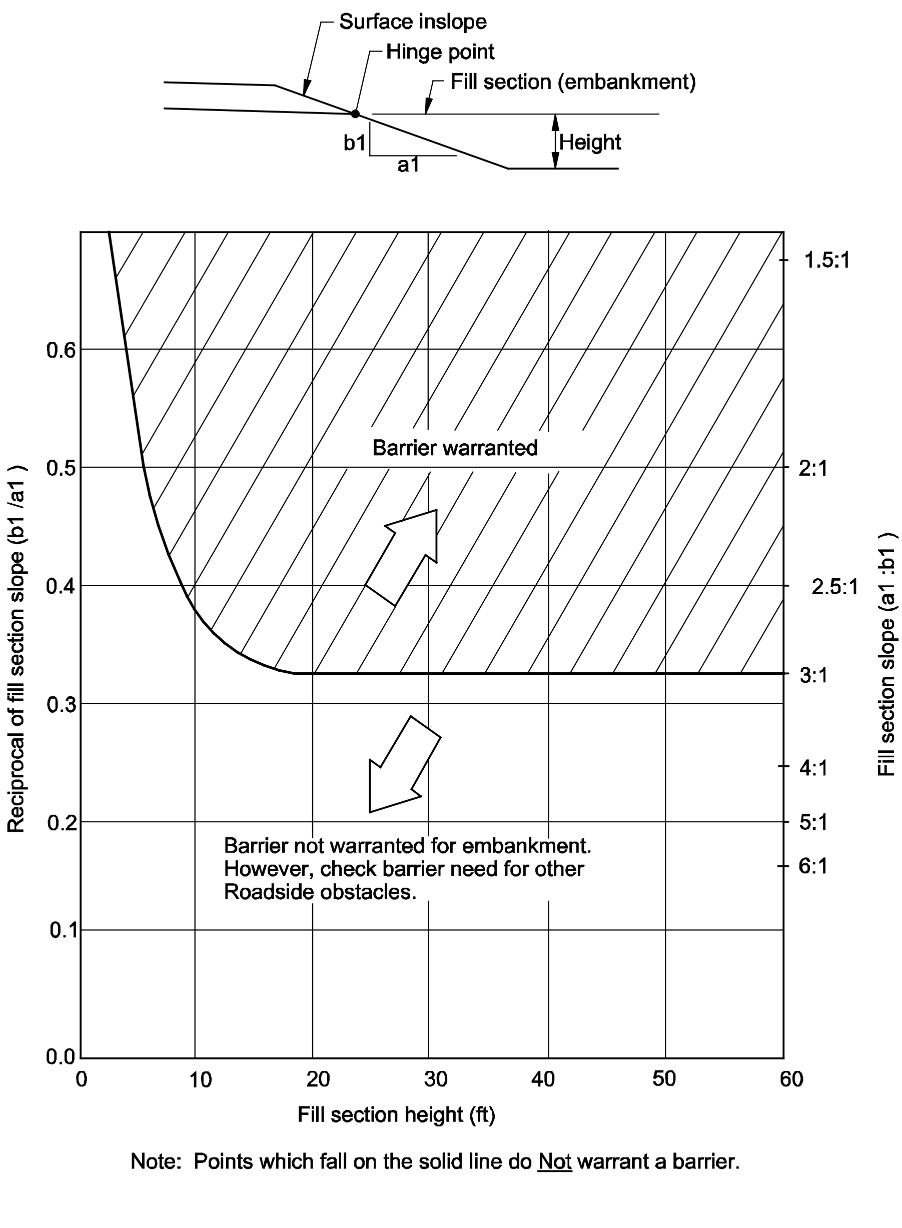
Traffic Direction	Bridge approach section Required at *
1 and 2	A B C D
2 only	A B
1 only	C D

* Approach rail locations C and B may not be appropriate for two-way facilities, if beyond the clear zone of the approaching traffic. Location, design speed, and crash history should be considered to determine if it is warranted.

9.3.2 Embankments

The severity of the roadside embankment depends upon the rate of fill slope and the height of fill. For all highways, use Exhibit 9-8 to determine if a barrier is warranted. For low embankment heights, the criteria allow fill slopes steeper than 3:1 to remain unshielded. A barrier is not required for areas outside of the shaded region, unless there are roadside obstacles within the clear zone as determined from Section 9.2.

Exhibit 9-8
Barrier Warrants for Embankments

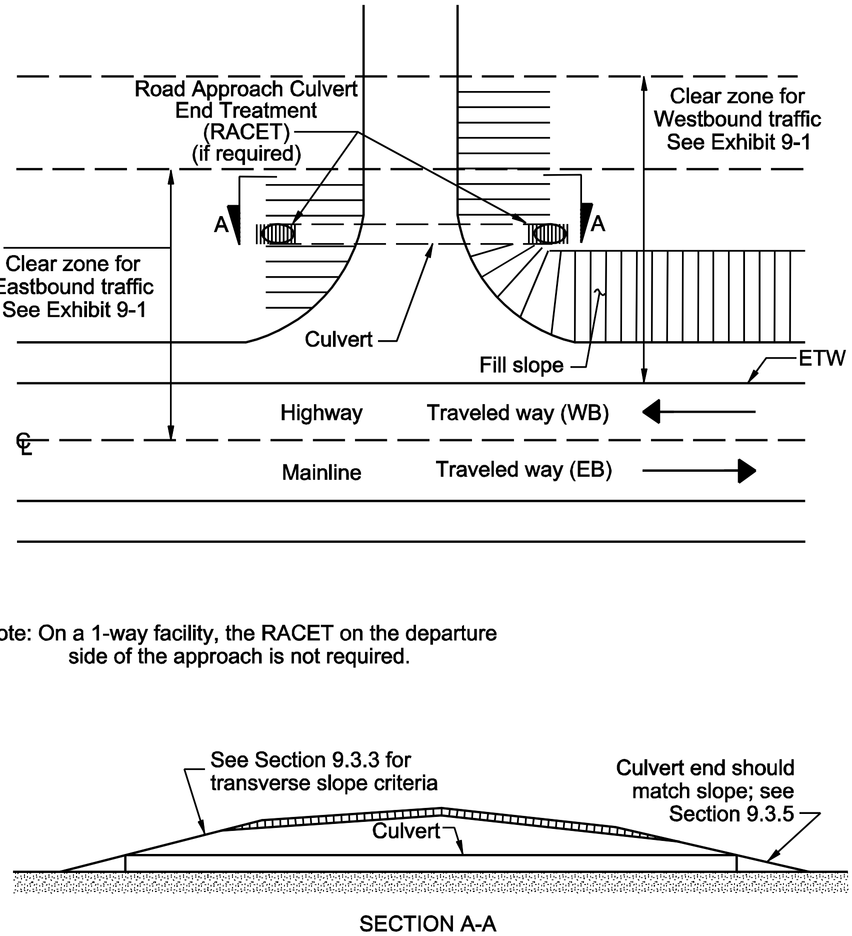


Note: Points which fall on the solid line do <u>Not</u> warrant a barrier.

9.3.3 Transverse Slopes

Where the highway mainline intersects an approach, side road, or median crossing, a slope transverse to the mainline will be present. Exhibit 9-9 provides an illustration. In general, transverse slopes should be as flat as practical.

Exhibit 9-9
Transverse Slopes



For slopes within the clear zone, the following will apply:

1. **Rural Conditions**. For rural (outside the boundaries of urban areas) roadways and urban roadways where the design speed is greater than 45 miles per hour, provide a transverse slope no steeper than 6:1. Transverse slopes of 10:1 are desirable where practical. Transverse slopes for median crossovers should be a minimum of 10:1, and 20:1 is desirable.
2. **Urban Conditions**. For roadways within the boundaries of an urban area where the design speed is less than or equal to 45 miles per hour, transverse slopes of 6:1 or flatter are desirable, where practical. Where necessary, steeper transverse slopes may be used to provide practical designs (e.g., urban facilities with closely spaced driveways).

Slopes may be transitioned to a steeper slope beyond the clear zone. Where these criteria cannot be practically met in rural areas, consider providing a roadside barrier. The decision to use a barrier will be made on a case-by-case basis considering costs, traffic volumes, severity of the proposed transverse slope, and other relevant factors (e.g., height of slope, crash history).

9.3.4 Rock Cuts

Rough rock cuts located within the clear zone may be considered a roadside obstacle. The backslope through rock cut sections is determined by the Geotechnical Section based on their field investigation. At a maximum, the backslope typically will not exceed 0.25:1. For large cuts, benching of the backslope may be required to remove loose overburden from the top of the formation material.

The following will apply to their treatment:

1. **Obstacle Identification**. There is no precise method to determine whether or not a rock cut is sufficiently "rough" to be considered a roadside obstacle. This will be evaluated on a case-by-case basis applying engineering judgment and documented accordingly.
2. **Debris.** A roadside obstacle may be identified based on known or potential occurrences of rock debris encroaching onto the roadway. If rock debris is expected within the clear zone, a barrier for capturing the debris may be required. Contact the Geotechnical and Maintenance Sections to determine the length, need, and type of barrier required.
3. **Barrier Warrant.** If the rock cut is determined to be an obstacle and it is within the clear zone, a barrier may be warranted.

9.3.5 Roadside Drainage Features

Effective drainage is one of the most critical elements in the design of a roadway. Drainage features should be designed and constructed considering their potential consequences on run-off-the-road vehicles. Ditches, curbs, culverts, and drop inlets are common drainage system elements that should be designed, constructed, and maintained considering both hydraulic efficiency and roadside safety.

In general, the following options, listed in order of preference, are applicable to all drainage features:

1. Construct or relocate outside the clear zone. For skewed culverts with end treatments that are not skewed, the design team should make sure all of the end treatment is outside the clear zone.
2. Design or modify drainage structures so that they are traversable or present a minimal hazard to an errant vehicle. For large culverts, it may not be cost effective to lengthen the pipe; therefore, building a pipe grate is an alternative. See Chapter 11 for drainage and end treatment designs. If the culvert has a Flared End Terminal Section (FETS), the opening is greater than the diameter of the pipe.
3. If a drainage feature, with an opening greater than 36 inches or including some other obstacle (e.g., a headwall), cannot effectively be redesigned or relocated, consider shielding it by a traffic barrier. In addition, consider a traffic barrier, if the feature is in a vulnerable location and if a barrier installation is judged to be cost effective.
4. Evaluate the condition, provide no corrective measure, and seek a design exception to document the obstacle located within the clear zone.

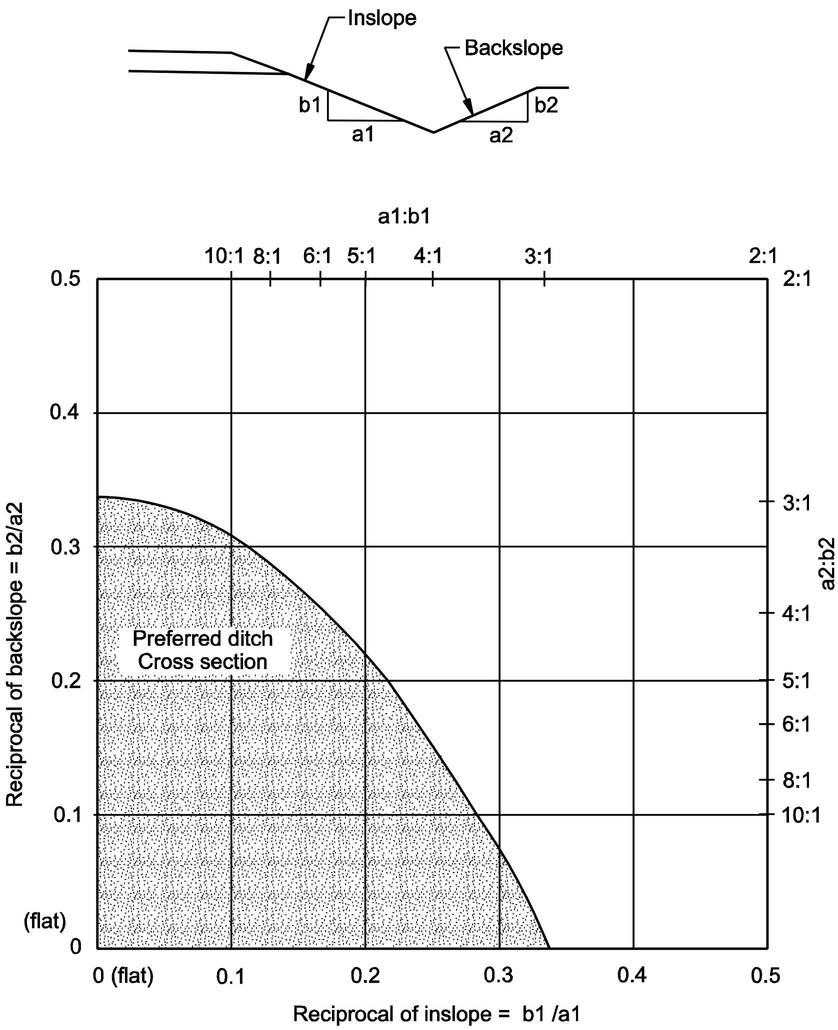
When shielding a point obstacle such as a culvert opening, the further from the roadway the obstacle is, the longer the length of guardrail needed to shield it. This results in a long crashworthy obstacle nearer the roadway to shield a point obstacle further from traffic. For this reason, FETS for smaller diameter pipes located in the clear zone are often left unshielded, and are instead documented in a design exception.

9.3.5.1 Roadside Ditches

Exhibits 9-10 and 9-11 present inslope and backslope combinations for basic ditch configurations. Cross sections which fall in the shaded region of each of the figures are considered traversable. Ditch sections which fall outside the shaded region are considered non-traversable and should be redesigned to an acceptable cross section; otherwise, consider providing a roadside barrier. For example, V-ditches with a 4:1 inslope require a 6:1 or flatter backslope to be traversable.

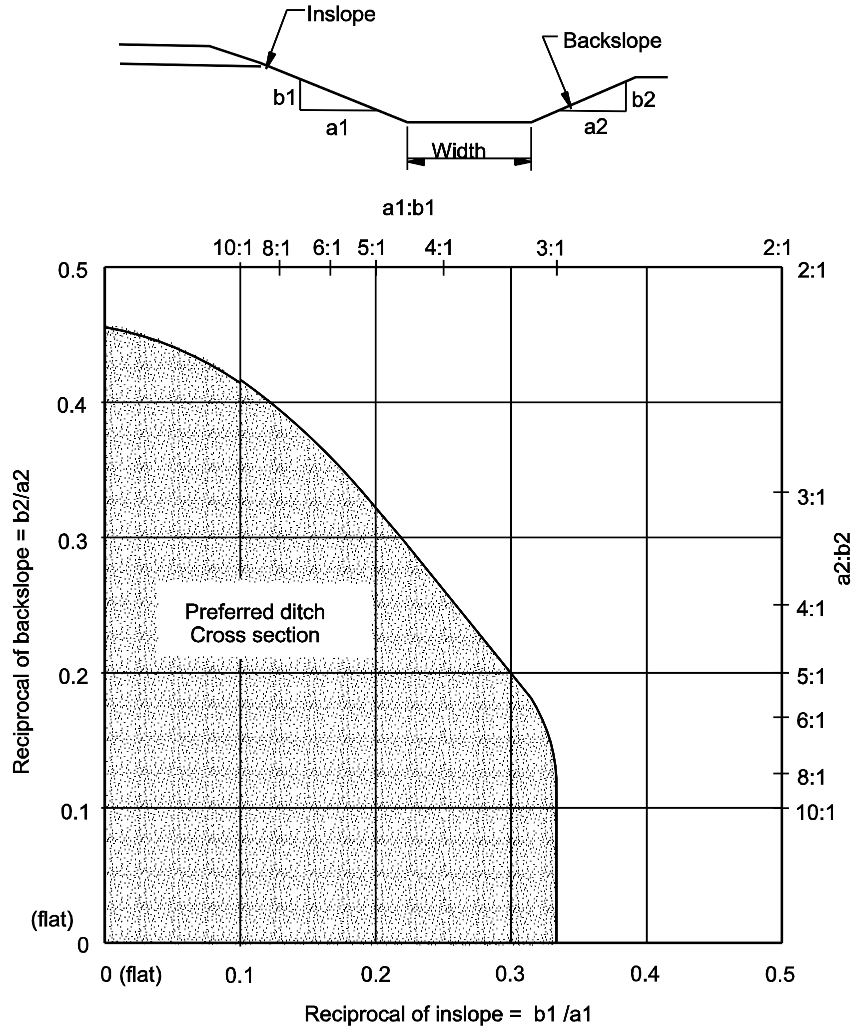
Chapter 5 presents additional information on the configuration of roadside ditches and how it relates to the overall roadway cross section. The *MDT Geometric Design Standards* provides MDT criteria for inslopes and backslope based on functional classification and design speed *(1)*. Chapter 11 provides more information regarding roadside and irrigation ditches. These ditch sections meet the traversability criteria in Exhibits 9-10 and 9-11.

Exhibit 9-10
Preferred Cross Section for Ditches



Note: This chart is applicable to all V-ditches, rounded ditches with a bottom width less than 8 feet, and trapezoidal ditches with bottom widths less than 4 feet.

Exhibit 9-11
Preferred Cross Sections for Ditches (With Gradual Slope Changes)



Note: This chart is applicable to all rounded ditches with a bottom width of 8 feet or more, and to trapezoidal ditches with bottom widths equal to or greater than 4 feet.

9.3.5.2 Curbs

Curbs are typically used for drainage control. In general, curbs should not be used on new construction projects in rural areas. Section 9.4.3 discusses the relative placement of curbs and guardrail. The *MDT Detailed Drawings* provide information on the different types of curbs used for MDT projects and the criteria for their placement.

9.3.5.3 Cross Drainage Structures

Cross drainage structures should be checked to determine if their inlets or outlets are within the clear zone. If an inlet or outlet is within the clear zone on a recoverable slope, the preferred treatment is to extend the structure so the obstacle is located beyond the clear zone. Extending the pipe on a recoverable slope may result in warping the side slopes to match the opening. Abrupt changes in parallel slopes should be avoided within the clear zone. Section 9.3.3

provides guidance on transverse slopes that should be considered. For larger skewed culverts, the edge protection may not be parallel with the roadway, and the culvert should be extended so that the 2:1 edge protection is entirely outside the clear zone.

Typically, it is not practical to extend a cross drainage structure so that the end is outside the clear zone when it is located on a non-recoverable slope. A recoverable barn-roof slope can be constructed having a slope that provides adequate clear zone width on top of the pipe.

Where extending the culvert is impractical due to site conditions, other treatments should be evaluated, such as shielding with a roadside barrier, flattening the slope to provide a recoverable slope, use of a modified end treatment, or requesting an exception to leave the obstacle.

For major drainage structures which are costly to extend, shielding with a roadside barrier may often be the most practical alternative.

9.3.5.4 Parallel Drainage Structures

Parallel drainage culverts are those which are oriented approximately parallel to the main flow of traffic. They are typically used under driveway approaches, field approach entrances, access ramps, intersecting side roads and median crossovers. As with cross drainage structures, the primary objective should be to locate the parallel drainage structure outside the mainline clear zone, to design generally traversable slopes, and to match the culvert opening with adjacent slopes. Section 9.3.3 provides the MDT guidance for transverse slope rates.

Openings of parallel drainage structures within the clear zone should match the selected side slope and be safely treated if practical. Although many of these structures are small and present a minimal target, the addition of a road approach culvert end treatment (RACET) with pipes and bars perpendicular to the mainline traffic can reduce wheel snagging in the culvert openings. The *MDT Detailed Drawings* provide additional details in the design of the RACET. Provide a RACET for any pipe with a diameter of 15 inches or greater which has any portion within the clear zone.

Parallel drainage structures may be closely spaced in urban areas because of frequent driveway approaches and intersecting roads. In such locations, it may be desirable to convert the open ditch into a closed drainage system and backfill the areas between adjacent driveway approaches. This treatment will eliminate the ditch section and the transverse embankments with pipe inlets and outlets.

9.4 ROADSIDE BARRIERS

When considering roadside barriers, the design team should ask the question: "Does the installation of a barrier reduce the severity of off-road crashes?"

9.4.1 Barrier Types

The following sections describe the non-proprietary roadside barrier types MDT uses. Refer to the *MDT Detailed Drawings* for detailed design information on each barrier type.

9.4.1.1 "W" Beam Guardrail

The "W" beam system with strong posts is a semi-rigid system. This system has a deflection distance of 4 feet. This guardrail system is the preferred system for high speed rural facilities where snow drifting is not a major concern. A major objective of the strong post system is to prevent a vehicle from "snagging" on the posts. This is achieved by using blockouts to offset the posts from the longitudinal beam and by establishing 6.25 feet as the maximum allowable post spacing for non-stiffened W-beam guardrail. Refer to the *MDT Detailed Drawings* for installation information and additional details on the types of "W" beam systems allowed for use on MDT facilities.

MDT has two guardrail "W" beam systems based on post types (wood and steel). Post selection for a project is at the Contractor's option. The Contractor is not required to use the same post type throughout the project. "W" beam systems used on curves less than 150 feet are required to be shop bent.

9.4.1.2 Low Tension Cable Guardrail

MDT does use pre-stretched, tensioned cable in some median applications. For those situations, the rail has to meet criteria *(NCHRP 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features, TL3)* and it has to be installed in accordance with the manufacturer's recommendations *(3)*. Three-cable guardrail is a flexible system with a large dynamic deflection (7 feet, 10 inches with 16 feet post spacing) tested with a 4,400 pound pickup truck. Most of the resistance to impact is supplied by the tensile forces developed in the cable strands. Upon impact, the cables break away from the posts, and the vehicle is able to knock down these posts as it is redirected by the cables. The detached posts do not contribute to controlling the lateral deflection. However, the posts which remain in place do provide a substantial part of the lateral resistance to the impacting vehicle and are therefore critical to proper performance.

Cable guardrail has a large dynamic deflection. Therefore, it can only be used where a deflection distance of 7 feet, 10 inches is available behind the cable guardrail for considerable lengths along the roadside. Cable guardrail is typically installed with mower strips (paved strip under the rail) and socketed post holes to aid in repair and maintenance of the system.

Its use should be tempered by the following considerations:

1. **Snow**. Cable guardrail is generally only used where there is a problem with snow drifting or removing snow during plowing operations.
2. **Transitions**. Do not use cable guardrail to transition into a bridge rail.
3. **Slopes.** Do not use cable guardrail on fill slopes steeper than 2:1, unless the distance between the back of the posts and the break in the fill slope is at least 8 feet. For fill slopes which are 2:1 or flatter, provide a minimum 2 foot shelf between the back of posts and the break in the fill slope.
4. **Minimum Radius.** If cable guardrail is used on the outside of sharp radius curves, the post spacing may need to be reduced. MDT does not allow low tension cable guardrail to be used on the inside of curves. See Exhibit 9-12 and the *MDT Detailed Drawings* for the applicable criteria.

5. **Maintenance**. In general, cable guardrail requires more maintenance after impact than the "W" beam guardrail. Therefore, the higher the probability of impact, the stronger the preference for the "W" beam system.

Exhibit 9-12
Cable Guardrail Post Spacing (On Outside of Horizontal Curves)

Centerline Radius	Maximum Post Spacing
≥ 700 feet	16 feet
≥ 440 feet & < 700 feet	12 feet
< 440 feet	Do not use cable guardrail

A low-tension three-strand cable barrier may also be used as a median barrier to contain and/or redirect errant vehicles. Median cable barrier is similar to standard cable barriers, but they have two cables on one side of the posts and one cable on the other side. These barriers may help address the risks of cross median crashes on divided highways with narrow medians. The low-tension cable guardrails are an option for use in locations where there is sufficient space to accommodate the large lateral deflections that may occur *(4)*. However, MDT typically uses proprietary pre-stretched, tensioned cable guardrail in medians in order to close crossovers that are left in place and for preventing cross median crashes.

9.4.1.3 Box Beam Guardrail

Box beam guardrail (weak post) is a semi-rigid system with a dynamic deflection of 3 feet, 9 inches. Resistance in this system is achieved through the combined flexure and tensile stiffness of the rail. Posts near the impact are designed to break or tear away, thereby distributing the impact force to adjacent posts.

Box beam guardrail is generally used in snow drift areas and areas that require substantial snow plowing where cable guardrail is not acceptable (such as on the inside of curves, where the 12-foot deflection distance required for cable guardrail is not available). Box beam guardrail used on curves with radii less than 715 feet should be shop-bent.

9.4.1.4 Concrete Barrier Rail

Concrete Barrier Rail (CBR) is typically used in narrow freeway medians to provide positive protection and separation of traffic. A tall wall barrier (46-inch barrier) may also be used in place of regular 32-inch barrier, if needed. The design team should check the line of sight over the barrier along the horizontal curves as described in Chapter 2, Section 2.8.1.1 to determine if the tall wall barrier is an appropriate installation. Anchored, cast-in-place CBR may also be considered on the roadside to shield rigid objects where minimal deflection distance is available (i.e., the object is less than 3.5 feet from the face of barrier). If a rigid object is not continuous (e.g., bridge piers), the design team may use a half-section CBR and provide the required installation details. All existing two-loop concrete barriers, including tall wall barrier, that needs to be moved for any reason during construction, must be replaced with *NCHRP 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features or Manual for Assessing Safety Hardware (MASH)* compliant concrete barriers *(3, 5)*. This includes barriers that would be moved temporarily to perform paving and replaced in its original location. Salvaged two-loop barrier may not be used on Federal-aid highway projects for temporary or permanent installations.

9.4.1.5 Stiffened Guardrail

The use of stiffened rail should be considered when there is insufficient deflection distance behind the ″W″ Beam rail to the obstacle. Stiffened rail can also be used to increase post spacing to avoid conflicts with buried objects, such as culverts. Stiffened guardrail is comprised of a combination of reduced post spacing on either side of the obstacle and doubled "W" beams. The use of different post spacing and doubled rail sections depend on whether a point obstacle or a line obstacle is being shielded.

Refer to the *MDT Detailed Drawings* for post and rail configurations.

9.4.2 Barrier Selection

9.4.2.1 Performance Criteria

The barrier performance-level requirements should be considered when selecting an appropriate roadside barrier. MDT uses *NCHRP 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features* and *MASH (3, 5)*.

Most barriers have been developed and tested for passenger cars and pickup trucks and offer marginal protection when struck by heavier vehicles at high speeds and more acute impact angles. Therefore, if passenger vehicles are the primary concern, the "W" beam, box beam, or cable guardrail systems will normally be selected. Locations with undesirable geometrics, high traffic volumes and speeds, high-crash experience, and/or a significant volume of heavy trucks and buses may require a higher performance-level barrier. This is especially important if barrier penetration by a vehicle is likely to have serious consequences.

9.4.2.2 Dynamic Deflection

The design team should also consider the dynamic deflection in barrier selection. Exhibit 9-13 provides the deflection distances for the various systems. If the appropriate deflection distance is not available, stiffen the railing system or use a CBR.

9.4.2.3 Maintenance

Another consideration in selecting the barrier type depends on maintenance of the system. Although the "W" beam can often sustain second hits, it should be repaired to standards and monitored frequently. In areas of restricted geometry, high speeds, high traffic volumes, and/or where railing repair creates hazardous conditions for both the repair crew and for motorists using the roadway, consider using the rigid CBR. The CBR also allows better control of roadside vegetation.

Exhibit 9-14 summarizes the advantages and disadvantages of the roadside barriers used on MDT facilities, as well as their typical usage.

Exhibit 9-13
Roadside Barrier Dynamic Deflection

Barrier Type	Dynamic Deflection Distances (Test Level 3)	Barrier Width	Min. Dist. From Face Rail to Obstacle
"W" Beam – Wood Posts	4'	1'-7"	5.6'
"W" Beam – Steel Posts	4'	1'-7"	5.6'
Stiffened "W" Beam – Point Obstacle 3'-1 ½" Post Spacing - Single Rail	2'	1'-7"	3.6'
Stiffened "W" Beam – Line Obstacle 1'-6¾" Post Spacing - Doubled Rail	1'-1"	1'-7"	2.7'
Nested "W" Beam – 25'-0" Span	5'	1'-7"	7.3'
Metal Guardrail – 7' Posts Posts spaced at 3'-1½" with 2:1 slopes and without widening	3'	1'-7"	4.6'
Low Tension Cable Guardrail	7'-10"	4" or 5"	12.0'
Box Beam Guardrail	3'- 9"	9"	4.5'
Concrete Barrier Rail[1]	4'-6"	2'-0"	6.5'
Anchored Concrete Barrier Rail	1'-6"	2'-0"	3.5'

[1]Please refer to MDT Concrete Barrier Rail research for additional information.

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Exhibit 9-14 Roadside Barrier Selection

SYSTEM	ADVANTAGES	DISADVANTAGES	TYPICAL USAGE
"W" Beam Guardrail	• Low initial cost. • High level of familiarity by maintenance personnel. • Can safely accommodate wide range of impact conditions for passenger cars. • Relatively easy installation. • Remains functional after moderate collisions.	• Cannot accommodate impacts by large vehicles at other than flat angles of impact. • At high-impact locations, will require frequent maintenance. • Susceptible to vehicular underride and override. • Susceptible to vehicular snagging (without rub rail).	• Non-freeways. • Freeways.
Low Tension Cable Guardrail	• Low initial cost. • Improved underride/override protection. • Can safely accommodate wide range of impact conditions for passenger cars. • Relatively easy installation. • Most forgiving of all systems.	• Cannot sustain a second impact. • Cannot accommodate impacts by large vehicles. • Cannot be used with curbing. • Requires significant maintenance after an impact. • Cannot be placed on inside of any horizontal curve or on outside of horizontal curves with radii less than 440 feet • Cannot be used to transition to bridge rail. • Large deflection distance required.	• Areas where there are problems with snow drifting and snow plowing.
Concrete Barrier Rail	• Can accommodate most vehicular impacts without penetration. • Little or no deflection distance required behind barrier. • Little or no damage sustained for most vehicular impacts; therefore, least need for maintenance. • No vehicular underride potential or snagging potential.	• Highest initial cost. • For given impact conditions, highest occupant decelerations; therefore, least forgiving of barrier systems. • Reduced performance where offset between traveled way and barrier exceeds 15 feet	• In front of rough rock cuts. • Where high traffic volumes are present. • Where high volumes of large vehicles are present. • Where snagging is a concern. • As a median barrier. • Where little or no deflection area is available.
Box Beam Guardrail	• Can be installed on the inside or outside of any curve. • Less deflection distance than cable guardrail. • Considered an aesthetic type of barrier.	• High initial cost. • Cannot sustain a second impact. • Cannot accommodate impacts by large vehicles. • Requires significant maintenance after impact. • Cannot be used with curbing.	• Areas where there are problems with snow drifting and snow plowing, and cable guardrail cannot be used.

9.4.3 Roadside Barrier Layout

9.4.3.1 Length of Need (General)

A roadside barrier should be extended a sufficient distance upstream from the obstacle (advancement length) to safely protect a run-off-the-road vehicle. Otherwise, the vehicle could travel behind the barrier and impact the obstacle. The design team should recognize that vehicles depart the road at relatively flat angles. Based on a number of field studies, the average angle of departure is estimated to be 10 degrees. The 80^{th} percentile is estimated to be 15 degrees. These flat angles of departure result in the need to extend the barrier a distance upstream of the obstacle.

The following equation is used to determine the total barrier length for a given roadside condition:

$$L_{TOTAL} = L_{ADJACENT} + L_{OBSTACLE} + L_{OPPOSING}$$

Equation 9.4-1

Where:

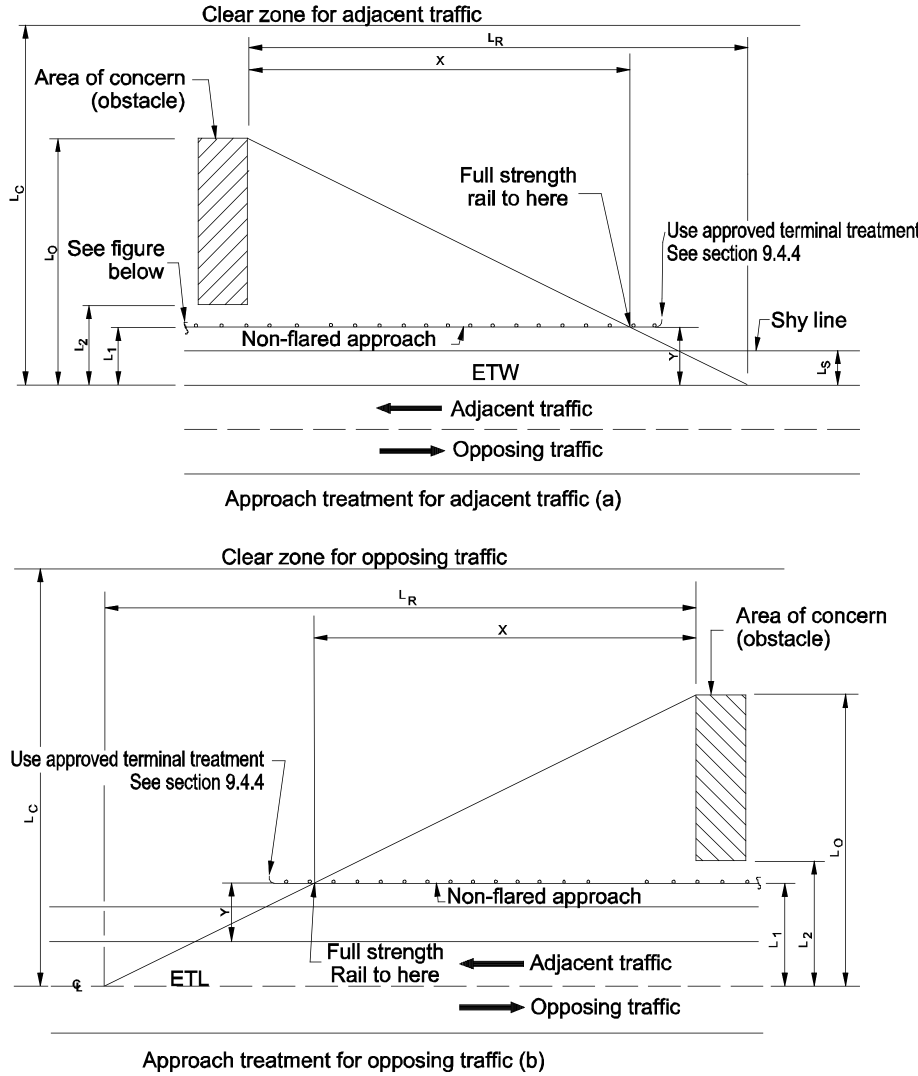
$L_{ADJACENT}$	=	The length needed in advance of the obstacle required to protect traffic in adjacent lanes.
$L_{OBSTACLE}$	=	The length of the obstacle itself.
$L_{OPPOSING}$	=	The length in advance of the obstacle needed to protect traffic in opposing lanes.

Only a portion of the terminal sections are included in the overall barrier length of need. See the *MDT Detailed Drawings* to determine the portion of the terminal section which may be included in the total length of need for the barrier.

Exhibit 9-15 illustrates the variables that should be considered in designing a roadside barrier to effectively shield an obstacle. As noted in the exhibit, the shy line is the distance from the edge of traveled way beyond which a roadside object will not be perceived as an obstacle. When a roadside object is perceived as an obstacle, the motorist may reduce their speed or change vehicle position on the roadway. Exhibit 9-15 illustrates the use of non-flared barrier design.

Where fill slopes change within the advancement length of the rail, calculate the advancement length using the clear zone for each traversable slope shown on the cross sections adjacent to the obstacle. Compare the results and use the location that produces the shortest length of rail. Generally, do not interpolate intermediate locations of slope changes between cross sections.

Exhibit 9-15
Barrier Length of Need



9.4.3.2 Length of Need
(Embankment/Obstacle That Extends to Edge of the Clear Zone)

Once the appropriate variables have been selected, the required length of need in advance of the obstacle can be calculated from Equations 9.4-2 and 9.4-3. These equations are used when the obstacle is an embankment or a fixed object which extends to or beyond the clear zone:

$$X = \frac{L_R (L_O - L_1)}{L_O}$$

Equation 9.4-2

$$Y = L_1$$

Equation 9.4-3

Where:

X, Y = coordinates of beginning of barrier need.

L_C = recommended clear zone.

L_O = distance from edge of traveled way to back of obstacle (i.e., the lateral extent of the obstacle). For a fixed object, the lateral extent of the obstacle (L_O) is the distance from the edge of the traveled way to the far side of the obstacle. If the obstacle is an embankment or a fixed object that extends beyond the clear zone, L_O is measured to the outside edge of the clear zone (L_C); i.e., L_O = L_C.

Exhibit 9-16
Design Elements for Barrier Length of Need

Design Speed (mph)	Runout Length L_R (ft) — Design Year Traffic Volume (AADT) >10,000	>5,000 ≤10,000	>1,000 ≤5,000	≤1,000	Shy Line Offset L_S (ft)
80	470	430	380	330	12
70	360	330	290	250	9
60	300	250	210	200	8
50	230	190	160	150	6.5
40	160	130	110	100	5
30	110	90	80	70	4

L_S = shy line offset or distance at which barrier is no longer perceived as an obstacle by a driver

L_R = runout length

L_1 = distance from edge of traveled way to face of barrier.

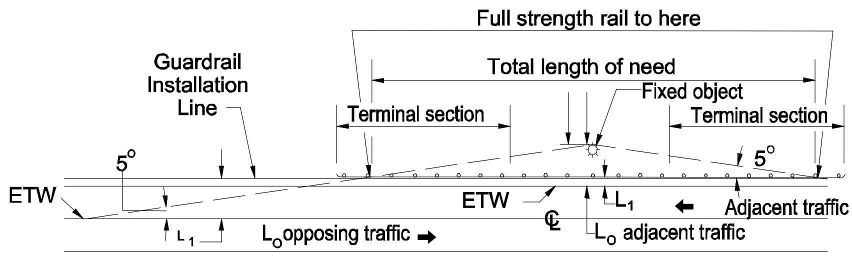
L_2 = distance from edge of traveled way to front of obstacle. ($L_2 - L_1$) should equal or exceed the deflection distance.

9.4.3.3 Length of Need (Obstacle Within Recoverable Clear Zone)

Use Equations 9.4-4 and 9.4-5 when the obstacle requiring shielding lies entirely within the clear zone, as illustrated in Exhibit 9-17.

Exhibit 9-17
Barrier Length of Need (Fixed Object Within Clear Zone

Note: Exhibit 9-17 is for a point obstacle only. For longer obstacles located entirely within the clear zone, add the length of obstacle to the length of need and calculate lengths of need from each end.



Equation 9.4-4

$$X = \frac{L_O - L_1}{\tan 5^\circ}$$

Equation 9.4-5

$$Y = L_1$$

Where:

- X, Y = coordinates of beginning of barrier need.
- L_O = distance from edge of traveled way to back of obstacle (i.e., the lateral extent of the obstacle).
- L_1 = distance from edge of traveled way to face of barrier.
- 5° = departure angle.

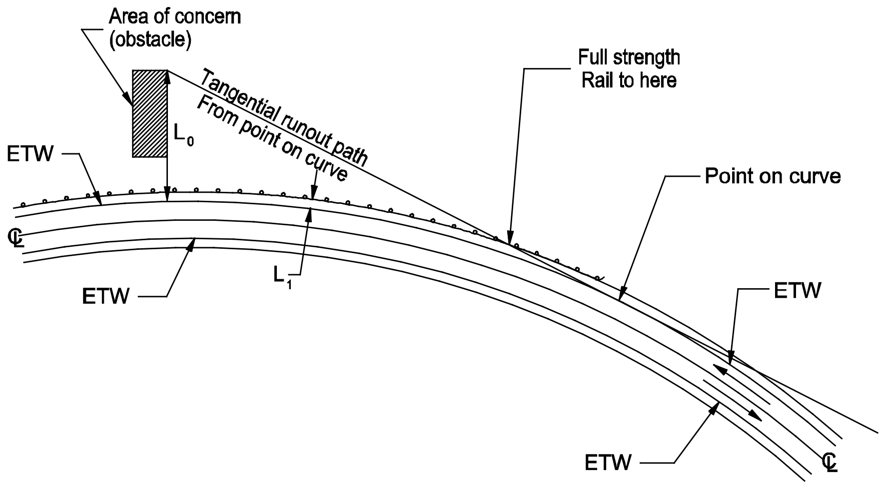
For two-way traffic, use these formulas for the approach treatment for both the adjacent and opposing traffic. For one-way traffic, use these formulas for the approach treatment of the adjacent traffic and extend the barrier to the far side of the obstacle.

For obstacles located near the clear zone limit, check the necessary barrier length using both the L_R formulas (Section 9.4.3.2) and the 5-degree angle formulas (Section 9.4.3.3). Use the method that produces the shorter overall length of barrier.

9.4.3.4 Length of Need (Horizontal Curves)

The length of need formulas (Equations 9.4-2 through 9.4-5) are applicable to tangent highway alignment and where the roadside obstacle is on the inside of a horizontal curve. A vehicle leaving the roadway on the outside of a horizontal curve will generally follow a tangential runout path. Therefore, rather than using the theoretical L_R distance to determine the length of need, use a tangent line from the edge of the traveled way to the outside edge of the obstacle. The length of need is determined by intersecting the barrier installation line with the tangent line, as shown in Exhibit 9-18. This intersection can most readily be obtained graphically. If the tangent line is less than L_R, use this intersection. However, if the tangent line is greater than L_R, use the L_R distance from the back of the obstacle to intersect the installation line to determine the adjacent length.

Exhibit 9-18
Barrier Length of Need
(Outside of Horizontal Curve)



9.4.3.5 Lateral Placement

Roadside barriers should normally be placed as far as practical from the edge of the traveled way. Such placement gives an errant motorist the best chance of regaining control of the vehicle without impacting the barrier. It also improves sight distance, particularly at nearby intersections. However, most barrier systems are installed at the edge of pavement to mitigate the shoulder widening necessary to provide a 10:1 (maximum) slope in front of the barrier as described in 9.4.3.7. Consider the following factors when determining barrier lateral placement:

1. **Deflection:** The dynamic deflection distance of the barrier, as measured from the face of the rail, should not be violated. Section 9.4.2.2 provides the deflection distances for the types of roadside barriers.
2. **Post Support.** At a minimum, provide 2 feet between the back of the barrier post and the slope break in a fill slope to provide adequate soil support for the post. If it is impractical to provide 2 feet behind the rail, long posts can be used on normal runs of rails (does not apply to bridge approach or terminal sections). The following options are available:
    a. **"W" Beam**
        i. 9-foot steel posts at the standard 6-foot, 3-inch spacing
        ii. 7.5-foot wood posts at the standard 6-foot, 3-inch spacing
        iii. 7-foot steel posts at 3-foot, 1.5-inch spacing
        iv. 7-foot wood posts at 3-foot, 1.5-inch spacing
    b. **Box Beam**
        i. 8-foot steel posts at the standard 6-foot spacing

Refer to the *MDT Detailed Drawings* for additional information.

3. **Shy Distance.** Barrier should be installed at the edge of the shoulder and should provide a minimum distance of 2 feet from the face of the rail to the edge of the traveled way. For some roadway widths, this practice will not meet the requirement of the shy line offset as presented in Exhibit 9-16. In these cases, installing the guardrail at the shy line offset distance is not practical and is not recommended.
4. **Shoulder Widening.** Provide a minimum distance of 2 feet between the edge of the traveled way and the face of the rail. If this distance is not available on the existing shoulder, additional widening will be necessary.

9.4.3.6 Placement in Conjunction With Curbs

For rural (outside the boundaries of urban areas) roadways and urban roadways where the design speed is greater than 45 miles per hour, do not place curbs in front of roadside barriers. Where curbs are used in conjunction with roadside barriers on low-speed facilities, the face of the barrier should be in line with the face of the curb (i.e., at the gutter line). Do not use curbs higher than 4 inches with a barrier on new construction facilities. Existing curb installations higher than 4 inches may remain if the installation otherwise meets MDT criteria. Measure the height of the barrier from the pavement surface (e.g., where curbs are on bridges). A weak post system, such as cable or box-beam guardrail, cannot be used in conjunction with curbing.

9.4.3.7 Placement on Slopes

Slopes in front of a barrier should be 10:1 or flatter. This also applies to the areas in front of the flared section of guardrail and to the area approaching the terminal ends. See the *MDT Detailed Drawings*.

9.4.3.8 Transitions

Barrier transitions are necessary to join two systems with different structural and/or dynamic characteristics. For example, this occurs when guardrail approaches a bridge parapet or CBR installation. The *MDT Detailed Drawings* provide details for the bridge approach section. See the *AASHTO Roadside Design Guide* for additional discussion on barrier transitions *(2)*.

9.4.3.9 Minimum Length/Gaps

Short runs of barrier have limited value and should be avoided. Generally, a barrier should have at least 100 feet of standard rail section exclusive of terminal sections and/or transition sections (does not include rail connected to structures or other blunt ends). Short gaps between runs of barrier are undesirable. Therefore, gaps of less than 165 feet between barrier termini should be connected into a single run. Exceptions may be necessary for access, or other project considerations.

9.4.4 Terminal Treatments

Barrier terminal sections present a potential roadside obstacle for run-off-the-road vehicles. However, they are also critical to the proper structural performance of the barrier system. The selection and design of the terminal end section should be carefully coordinated with the barrier system's purpose and length of need. The design team should review the *MDT Detailed Drawings* or manufacturer's specifications to determine what portion of the terminal section can be applied to the length of need.

New terminal systems are continually emerging to address safety problems, and devices are being improved in response to an increased understanding of safety performance, a changing vehicular fleet, the emergence of new materials and other factors.

See the *MDT Detailed Drawings* for details on the design and placement of acceptable roadside hardware.

9.4.5 Roadside Hardware Supports (Mailbox Supports)

Where roadside hardware (e.g., sign supports, illumination poles, traffic signal poles, mailboxes) cannot be reasonably located outside of the clear zone, they should be made breakaway or shielded with a roadside barrier or impact attenuator. This section discusses the criteria specifically for mailbox supports. For sign supports and luminaires, the design team should coordinate with the Traffic Engineering Section.

Mailboxes and newspaper tubes served by carriers in vehicles may constitute a roadside obstacle, depending upon the placement of the mailbox. The design team should make every reasonable effort to replace all non-conforming mailboxes with the designs that meet the criteria in *A Guide to Mailbox Safety in Montana*, the *AASHTO A Guide for Erecting Mailboxes on Highways*, and the *MDT Detailed Drawings (6)*.

In general, mailboxes should meet the following criteria:

1. **Heights.** Mailbox heights are usually located so that the bottom of the box is 3.3 feet to 4 feet above the mail stop surface.
2. **Post.** The maximum strength supports that should be used are nominal 4-inch-by-4-inch wood posts or 4-inch diameter wood posts or 2-inch diameter standard galvanized steel pipe post, embedded no more than 2 feet into the ground. The use of concrete anchors is not acceptable.
3. **Multiple Mailboxes.** To reduce the possibility of ramping, multiple mailboxes should be separated by a distance at least equal to three-fourths of their height above ground.
4. **Neighborhood Delivery and Collection Box Units (NDCBU).** NDCBU is a cluster of 8 to 16 locked boxes mounted on a pedestal or within a framework. Because the total mass for the NDCBU may range between 100 pounds and 200 pounds, they are considered a roadside obstacle. NDCBUs are intended to be located in trailer parks, apartment complexes and new residential subdivisions. If there is no alternative, locate NDCBUs on low-speed facilities in conjunction with mailbox turnouts and outside of the clear zone.

Ramping is the result of objects (e.g., multiple mailboxes) forming an inclined surface that can cause a vehicle to vault during a collision.

9.5 MEDIAN BARRIERS

9.5.1 Warrants

The following summarizes MDT median barrier criteria:

1. **Freeways.** Exhibit 9-19 presents the warrants for a median barrier based on median width and traffic volumes. The traffic volumes are based on a minimum 5-year projection. In the areas shown as optional, the decision to use a median barrier will be based on construction and maintenance costs and crossover crash experience. A median barrier may be warranted on medians not within the optional or warranted area, if a significant number of crossover crashes have occurred.
2. **Non-Freeways.** On other highways, judgment should be used to determine median barrier warrants. On highways without full access control, the median barrier should be terminated at intersections where it has been determined that an opening will be provided. In addition, lower speeds will reduce the likelihood of crossover crashes. Therefore, on non-freeway highways, the design team should evaluate the crash history, traffic volumes and speeds, median width, alignment, sight distance, and construction costs to determine the need for a median barrier. Exhibit 9-19 can be used for guidance.

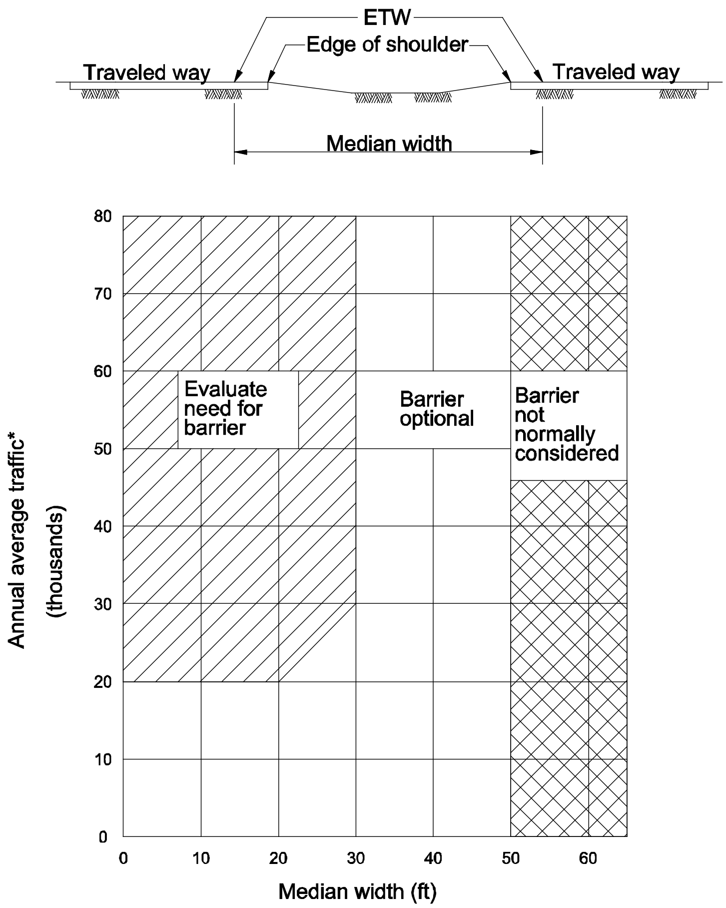
9.5.2 Types

When a median barrier is warranted, due to narrow medians, MDT's policy is to only use a Concrete Barrier Rail (CBR). The CBR is a rigid system which will rarely deflect upon impact. A half-section CBR may be necessary where the median barrier should divide to go around a fixed object in the median (e.g., bridge piers). In this situation, the obstacle is typically encased within concrete to create a level surface from CBR face to CBR face.

The "W" beam guardrail is typically used within the median to protect the driver from isolated obstacles (e.g., bridge approaches or piers). The design team should review Section 9.4.3 and the *MDT Detailed Drawings* for the design and placement criteria of "W" Beam guardrail within the median; i.e., the median is treated as a "roadside" in these cases.

MDT has used pre-stretched, tensioned cable within the median to address crossover crashes and to close median crossovers left in place. For such installations, MDT requires the posts be socketed for ease of maintenance, and require the rail meets TL-3 criteria. Use information provided in the *AASHTO Roadside Design Guide* for additional guidance on best practices for placement in the median *(2)*.

Exhibit 9-19
Median Barrier Warrants



* Based on a minimum five-year projection

9.5.3 Median Barrier Layout

Much of the information presented in Section 9.4.3 on roadside barrier layout also applies to concrete median barriers (e.g., length of need, flare rates). The following presents criteria specifically for the layout of concrete median barriers:

1. **Flared/Divided Median Barriers**. It may be necessary to intermittently divide a median barrier or to flare the barrier from one side to the other to shield a fixed object in the median. The fixed object may be shielded by one of these methods:
    a. A fixed object may be encased by a CBR.
    b. A half-section CBR may be used on both sides to shield a fixed object.
2. **Barrier-Mounted Obstacles**. If trucks or buses impact the CBR, their high center of gravity may result in a vehicular roll angle which possibly will allow the truck or bus to impact obstacles on top of the CBR (e.g., luminaire supports). If practical, move these devices to the outside and make them breakaway, or provide additional distance between the barrier and obstacle by using a flared/divided median barrier.

3. **Terminal Treatments**. As with roadside barrier terminals, CBR terminals also present a potential roadside obstacle for run-off-the-road vehicles. Give careful consideration to the selection and placement of the terminal end. For the terminal ends of concrete barrier rail, see *MDT Detailed Drawings.* See Section 9.6 for more information on end treatments.

9.6 END TREATMENTS

9.6.1 General

End treatments are protective systems that prevent errant vehicles from impacting fixed obstacles by either decelerating the vehicle to a stop after a frontal impact or by redirecting it away from the obstacle after a side impact. The *AASHTO Roadside Design Guide* describes three types of end treatments, including: Anchorages, Terminals and Crash Cushions (Impact Attenuators) *(2)*.

Anchorages are devices that anchor a flexible or semi-rigid barrier to the ground to develop its tensile strength during an impact. This type of end treatments is not considered crashworthy; therefore, they are typically only used on a trailing end of a barrier on a one-way roadway or on a barrier that is located outside of the clear zone. Terminals are similar to anchorages, as they also anchor a barrier to the ground. Terminals are considered crashworthy and are typically used at the end of a barrier within the clear zone *(2).*

Impact attenuators, which are also known as crash cushions, can be attached to or placed in front of concrete barrier rails or other rigid fixed objects. Impact attenuators are also adaptable to many roadside obstacle locations where longitudinal barriers cannot practically be used (e.g., bridge piers and non-breakaway sign supports). Section 9.4.4 previously discussed various types of terminal treatments. The remainder of this section provides details for impact attenuators.

9.6.2 Warrants

Impact attenuator warrants are the same as barrier warrants. Once an obstacle is identified, the design team should first attempt to remove, relocate, or make the obstacle break away. If the foregoing is impractical, then consider an impact attenuator.

Impact attenuators are most often installed to shield fixed-point obstacles which are too close to the traveled way to allow room for other types of barriers and are more likely to sustain a head-on impact. Examples include exit gore areas (particularly on structures), bridge piers, and non-breakaway sign supports. Impact attenuators are often preferable to guardrail to shield these obstacles. Site conditions and costs will determine whether to use a barrier or impact attenuator. Impact attenuators are the only type of terminal section used for CBR requiring an end treatment.

9.6.3 Impact Attenuator Types

Refer to the *MDT Detailed Drawings* for information on the types of acceptable impact attenuators. All impact attenuator types are patented, and the design team should contact the manufacturer for additional information on impact attenuator installations.

9.6.4 Impact Attenuator Design

Once an impact attenuator has been selected, the design team should ensure that its design is compatible with the traffic and physical conditions at the site. The following sections will provide criteria for the basic input parameters for impact attenuator design.

9.6.4.1 Performance Criteria

All impact attenuators must be certified as having passed the performance criteria in *NCHRP Report 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features* or *MASH (3, 5)*.

9.6.4.2 Design Procedures

Refer to the *MDT Detailed Drawings* for the lengths required for each design speed to determine the appropriate length of the different impact attenuators approved for use by MDT.

9.6.4.3 Placement

Several factors should be considered in the placement of an impact attenuator:

- **Level terrain.** All impact attenuators have been designed and tested for level conditions. Vehicular impacts on devices placed on a non-level site could result in an impact at the improper height which could produce undesirable vehicular behavior. Therefore, the attenuator should be placed on a level surface or on a cross slope not to exceed 5 percent.
- **Curbs.** No curbs should be present on new projects at proposed impact attenuator installations. On existing highways, all curbs should be removed at proposed installations if feasible, particularly those that are 4 inches or higher.
- **Surface**. A paved, bituminous or concrete pad should be provided under the impact attenuator.
- **Orientation**. The impact attenuator should be oriented to accommodate the probable impact angle of an encroaching vehicle. This will maximize the likelihood of a head-on impact. The proper orientation angle will depend upon the design speed, roadway alignment and lateral offset distance to the attenuator. An angle of 5 degrees to 10 degrees, as measured between the highway and impact attenuator longitudinal centerlines, may be appropriate. See the manufacturer's data for more information.

- **Reserve Area.** The design team should, as early as practical in the project design process, determine the need for and approximate dimensions of impact attenuators. This will avoid late changes which could significantly affect the project design.

9.7 REFERENCES

1. Montana Department of Transportation (MDT). *MDT Geometric Design Standards.* MDT, Helena, MT, 2016.
2. American Association of State Highway and Transportation Officials (AASHTO). *Roadside Design Guide, 4th Edition*. AASHTO, Washington, D.C., 2011.
3. Ross, Jr., H. E., et. al. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* TRB, National Research Council, Washington, D.C., 1993.
4. Marzougui, D., et. al. *Performance Evaluation of Low-Tension Three-Strand Cable Median Barriers.* Transportation Research Board of the National Academies, Washington, D.C., 2007.
5. AASHTO. *Manual for Assessing Safety Hardware (MASH)*. AASHTO, Washington, D.C., 2009.
6. AASHTO. *A Guide for Erecting Mailboxes on Highways.* AASHTO, Washington, D.C., 1994.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 10

Work Zone Traffic Control

September 2016

Contents

Chapter 10

Work Zone Traffic Control

Traveling through a construction zone can be difficult and confusing to drivers. A well-planned traffic control design can alleviate many of these difficulties and confusions. This chapter provides information for developing a safe and well-conceived transportation management plan (TMP), including construction options, geometric design of crossovers and detours, and roadside safety through construction zones.

10.1 DESIGN PRINCIPLES AND APPROACH

The primary function for temporary traffic control is to provide for the safe and efficient movement of roadway users through or around work areas while protecting construction personnel and equipment, and allowing for efficient construction and maintenance of the facility. Key principles are, but not limited to, the following:

- Develop clear signage and pavement markings well in advance and through the construction area;
- Avoid frequent and/or abrupt changes in roadway geometry and/or speed;
- Use traffic control devices that highlight and emphasize the appropriate path; and
- Minimize the inconvenience to traffic during construction.

The TMP must provide an appropriate design that meets traveler expectation, but additional risk may be assumed due to the temporary nature of this type of design. The design team should work closely with the Traffic and Safety Bureau and construction personnel to communicate the intent and limitations of temporary design features and ensure that this is then communicated to the public that these areas can be navigated with additional caution.

The *MDT Work Zone Safety and Mobility (WZSM) Policy* provides the goals and objectives, guidelines, procedures, and processes related to work zone safety and mobility for MDT employees, construction workers, and the public (*1*). The vision for the WZSM Policy is to plan, design, construct, and maintain highway construction zones that optimize work zone safety and roadway user mobility while minimizing stakeholder and environmental impacts.

The WZSM Policy includes five goals, each with their respective objectives and performance indicators. The goals are:

1. Reduce the number and severity of crashes, injuries and fatalities in construction zones;
2. Monitor and continually improve current management practices of construction and maintenance operation roadway user impacts;
3. Ensure appropriate level of knowledge, skills, and abilities for responsible parties to manage and evaluate construction zone safety and mobility;
4. Minimize stakeholder impacts; and
5. Optimize construction zone traffic control design and implementation.

All construction and maintenance work on MDT facilities requires a TMP, and the amount of detail that is included in the TMP depends on the anticipated level of impact of the construction zone. The plans will include up to three components, depending on the level of impact: a traffic control plan (TCP), transportation operations (TO), and public information (PI). The TCP describes measures within the contract to facilitate roadway users through a construction zone, work zone, or an incident area, and it addresses traffic safety and control through the construction and work zone. The TO plan includes the identification of strategies used to mitigate impacts of the construction zone on the operation and management of the transportation system within the construction zone impact area. The PI component of the TMP includes communication strategies that seek to inform affected roadway users, the general public, area residences and businesses, and appropriate public entities about the project, the expected construction zone impacts, and the changing conditions of the project. This chapter primarily covers the TCP, as it is the most directly relevant to roadway design.

There are three levels of impact of the construction zone:

- Level 1: Significant regional impact for highway users and businesses.
- Level 2: Moderate, localized impact to highway users, businesses, and adjacent properties.
- Level 3: Little to no impact.

More information can be found in the WZSM Policy.

Work Zone Safety and Mobility

10.2 TRAFFIC MANAGEMENT

Highway construction will disrupt normal traffic operations; therefore, MDT requires every project to address traffic control through construction zones. This may range in scope from very detailed plans to merely referencing the *MDT Detailed Drawings* and the *Manual on Uniform Traffic Control Devices (MUTCD) (2)*.

With much of MDT's highway program involved in upgrading existing highways, a comprehensive traffic control plan is essential. This will minimize the operational and safety challenges through the construction zones.

10.2.1 Responsibilities

MDT requires a coordinated effort from various units to implement a successful TCP through construction zones. The following discusses the responsibilities of these MDT units:

- **Preconstruction**. Preconstruction will consist of the design team working in collaboration with District traffic and construction staff. The responsibilities of the Preconstruction staff include, but are not limited to, the following:
    a. Determining the sequence of operations, the need for detours, crossovers, and lane closures that will be used in the project;
    b. Providing at least one acceptable construction method that can be used on the project;
    c. Developing the geometric design for specially constructed detours, lane closures and crossovers;
    d. Developing draft special provisions for traffic control and sequence of operations;
    e. Ensuring that a detailed review is given to the proposed TCP during the project design plan reviews;
    f. Providing quantities for temporary pavement markings, detours, crossovers, temporary guardrail, and other traffic control items to be paid for with specific bid items; and
    g. Revising Traffic Control estimates as appropriate.
- **Construction Oversight.** Construction Oversight will consist of the District traffic/construction staff working in collaboration with the design team. The responsibilities of the Construction Oversight staff include, but are not limited to, the following:
    a. Developing the detailed TCP for the project;
    b. Ensuring that the proper selection and placement of traffic control devices occurs (e.g., pavement markings, barricades, signing);
    c. Addressing the roadside safety concerns through the construction zones (e.g., construction clear zones, temporary barriers, placement of construction equipment and supplies);
    d. Making provisions for informing the public through various media options of the necessary project information (e.g., proposed road closure); and
    e. Providing quantities for traffic control devices.

10.2.2 Evaluations

The objective of the TCP is to provide a strategy that will efficiently and safely move traffic through or around the construction zone. The design team should coordinate with the Construction Section when preparing a TCP. For projects impacting the operations of the system beyond the project or for modified use of existing facilities, the design team should coordinate with the Traffic and Safety Bureau when preparing a TCP. To accomplish this strategy, evaluate the following when preparing a TCP:

- **Preliminary Review**. Conduct a preliminary discussion of the TCP during the Preliminary Field Review. The discussion should include, but is not limited to, items such as methods of traffic control that will be feasible for the project, location of detours, and duration of various construction aspects.
- **Engineering.** Some of the engineering aspects to consider include:
  a. **Highway Capacity**. The TCP should provide adequate capacity to handle the expected traffic volumes through the construction zone or detour at an acceptable level of service. This may require converting shoulders to travel lanes, eliminating on-street parking, constructing temporary lanes, opening additional lanes during peak periods, or providing public transportation.
  b. **Geometrics**. The TCP should have suitable geometry so that a driver can safely maneuver through the construction zone, day or night. Frequent and abrupt changes in geometrics, such as crown changes, lane narrowing, lane drops or mainline transitions that require rapid maneuvers, should be avoided. Section 10.4 presents geometric design criteria for construction zones.
  c. **Roadside Safety**. Providing a safe environment both for the traveling public and construction workers is an essential element through construction zones. Traffic safety through construction zones should be an integral and high priority of every project from planning through design and construction. Section 10.5 addresses roadside safety challenges through construction zones.
  d. **Overhead Lighting**. If the existing roadway has overhead lighting, it must be maintained during construction.
- **Constructability.** The design team should evaluate the proposed construction sequence to determine if the project can be constructed based on the proposed TCP. Some of the elements the design team should evaluate include:
  a. Whether traffic will be able to safely maneuver through all the proposed intermediate horizontal and vertical alignment steps;
  b. The location of adjacent traffic relative to worker and traffic safety;

   c. Whether there is sufficient room for equipment maneuverability, as well as access locations for construction traffic; and
   d. Whether the construction phasing is appropriate.

- **Construction.** There are several construction options available that will improve the TCP. These should be discussed during the design phase of the project. Some of these options include:
   a. The use of special materials (e.g., quick curing concretes that will allow traffic within hours of pouring);
   b. The use of special designs (e.g., using precast box culverts versus cast-in-place box culverts or bridges);
   c. Requiring special scheduling requirements which will reduce traffic disruptions (e.g., working at night, lane closure during off-peak periods);
   d. Developing project phasing plans which will allow traffic to use the facility prior to project completion; and
   e. Contractor alternate bidding methods such as A+B bidding or cost incentives/disincentives for early/late completion of construction may be useful for projects having significant traffic control issues. Where there is Federal Highway Administration (FHWA) oversight, these methods must be justified and approved by FHWA.

A+B Bidding: This cost-plus-time method of bidding enables the contractor to determine a reasonable contract duration required for project completion; thus allowing the contractor to control the important element of time.

- **Operation Selection.** The initial determination on whether the project will require detours, lane closures, crossovers, and temporary closures should be made during the Preliminary Field Review (PFR). Section 10.3 provides additional guidance for determining which of these various construction applications may be appropriate.
- **Business.** In urban areas, an in-depth public involvement plan is necessary to coordinate the TCP with local businesses. If at all possible, access to at least one of any business's approaches must be maintained during business hours.
- **Maintenance.** Include provisions describing how the road will be maintained and who will be responsible for snow removal during winter conditions.
- **Pedestrians and Bicycles.** Safe accommodation of pedestrians and bicyclists through the construction zone should be addressed early in project development. Situations that would normally warrant special pedestrian and bicyclist considerations may include locations where sidewalks traverse the construction zone, where a designated school route traverses the construction zone, where significant pedestrian and bicyclist activity or evidence of such activity exists and where existing land use generates pedestrian and bicyclist activity (e.g., parks, schools, shops).

Consider the following principles when addressing pedestrian and bicycle accommodation through construction zones:

a. Physically separate pedestrians and vehicles from each other.
b. Ensure pedestrian walkways and bicycle paths are free of any obstructions and hazards (e.g., holes, debris, mud, construction equipment, stored materials).
c. Consider temporary lighting for all walkways that may be used at night, particularly if adjacent walkways are lit.
d. Clearly delineate all hazards (e.g., ditches, trenches, excavations) near or adjacent to walkways.
e. Evaluate whether walkways under or adjacent to elevated work activities (e.g., bridges, retaining walls) need to be covered.
f. Where pedestrian walkways and bicycle paths cannot be provided, then direct pedestrians and bicyclists to an alternative safe location (e.g., the other side of the street).
g. Stage construction operations so that, if there are two walkways, they are not out of service at the same time.
h. Plan the construction so that any temporary removal of sidewalks in front of land uses such as businesses and schools can occur in the shortest amount of time practical or be scheduled around non-peak pedestrian times (e.g., summer construction around schools).
i. Ensure that all temporary sidewalks meet the handicapped accessibility requirements for surface, curb ramps, sidewalk cross slopes, longitudinal slopes, etc. For more information on handicapped accessibility criteria, see Chapter 1, Section 1.5.1, Chapter 7, Section 7.3.2, and the *MDT Geometric Design Standards* (*3*).

Refer to Chapter 6 of the MUTCD for additional guidance regarding pedestrian and bicycle facilities in construction zones.

- **Heavy Vehicles.** Oversized vehicles are often detoured around construction sites or staged for passage through the construction zone during designated periods. The design team should consider the horizontal clearance if temporary concrete barrier rail (TCBR) is installed along both sides of the temporary roadway to accommodate oversize/overweight heavy vehicles. The design team should provide 14 feet of width, if possible. Evaluate the need for and placement of wide load detours, signing and other considerations during the Preconstruction TMP process. Consider coordination with Motor Carrier Services for potential wide load restrictions and/or posting width restrictions on the MCS website.

10.2.3 Documentation

The design team should document the proposed traffic control methods and features in each milestone report as described in the report templates and on the TMP worksheet, if applicable.

In addition to general information, provide specific design information when traffic control for a project will require variations from design guidance provided in this chapter, when using existing routes or modifying full buildout features for detouring traffic, and when unique or complex traffic control features are used. More information on these reports can be found in Chapter 1, Section 1.3.4, and at the following link on the MDT Website.

Project Reports

10.3 CONSTRUCTION APPLICATIONS

The following sections present several construction applications that the design team should consider when developing the project phasing. The several variables that affect the needs of the construction zone include location of work, roadway type, speed, traffic volume, geometrics, vertical and horizontal alignment, pedestrians, bicycles, oversize/overweight trucks, and intersections. The design team should understand that each construction zone is different and that not all applications will apply on every project. For most projects, there may be more than one alternative. Typical applications should be altered to fit the conditions of the particular construction zone. All temporary traffic control features must be in accordance with the *MUTCD (2)*.

10.3.1 Work Outside of the Roadway

Traffic will generally not be impeded when the construction area is outside of the roadway. The design team should ensure that there are enough access points available to the contractor to allow for construction equipment to exit, enter, or cross the highway in a safe manner. Sufficient sight distance should be available to both the motorist and the equipment operator.

10.3.2 Shoulder Work and Partial Lane Closures

Shoulder work which does not encroach into the travel lane will generally have minimal impact on traffic if proper signing is provided to advise the motorist. Workers may require protection with the appropriate channelizing devices, temporary barrier and/or a truck-mounted attenuator. Work spaces should be closed off by a taper or channelizing device with the appropriate length as provided in Section 10.4.3.

Partial lane closures may be appropriate where there are:

- Short construction durations;
- Minimal hazardous conditions (e.g., no drop-offs greater than 6 inches next to the roadway); and
- Minimal impacts to traffic.

Where partial lane closures are used, the remaining lane width should be 11 feet. However, a 10-foot lane width may be used on low-volume roadways that have low truck volumes. Use full-lane closures rather than partial lane closures where there is a substantial volume of wider vehicles (e.g., trucks, buses, recreational vehicles) or where construction is adjacent to high-speed traffic. The following sections provide information for full lane closures.

10.3.3 Lane Closure (Two-Lane Highways)

Lane closures on two-lane highways will generally require shifting traffic to the shoulder or providing traffic for both directions on a one-lane roadway through the use of flaggers and pilot cars. The design team should consider alternative treatments (e.g., detours based on duration and length of the lane closure and the traffic volume).

Where detours are impractical, consider reconstructing existing shoulders to allow them to be used as a temporary traffic lane. Proper signing and pavement markings with the appropriate geometry are necessary to shift traffic to the appropriate locations. See Section 10.3.7.

Based on the duration and length of the detour and on the traffic volume, the use of alternating traffic on one-lane roads may be acceptable. This strategy is commonly used with the reconstruction of low-volume bridges where each side is reconstructed in separate phases. Adequate sight distance and signing must be available at the site to ensure the motorist understands the appropriate action to take. For daily closures, flaggers may be used to control traffic through the site. For long-term closures, consider using temporary traffic signals to control traffic through the construction zone.

10.3.4 Single-Lane Closures (Four-Lane Highways)

Single-lane closures on divided facilities may be appropriate if:

- They will only cause minor delays during peak time periods, and
- The construction will not result in a substantial increase in hazards to traffic and/or construction personnel.

In urban or other high-volume areas, consider reconstructing and shifting traffic to the shoulder or reducing lane widths to maintain both lanes of traffic in each direction through the construction area. If narrower lanes are used, ensure wide loads can still be accommodated (e.g., alternative routes are available). All lane shifts should meet the taper lengths presented in Section 10.4.3.

10.3.5 Two-Way Traffic on Divided Highways

10.3.5.1 Guidelines

The decision on when to use two-way traffic on one of the two roadways of a divided highway will be made on a project-by-project basis. The input of Construction personnel is essential. In making this decision, consider the following factors:

- **Lane and Shoulder Widths.** The minimum allowable lane and shoulder widths are dependent on the volume of traffic and the percentage of trucks. Use Exhibit 10-1 to determine the shoulder width of the single roadway.

Exhibit 10-1
Shoulder Width Criteria

DHV for 12-Foot Lane Widths	Shoulder Width
1000	4 feet or greater
800	2 feet
700	0

- **Construction Efficiency**. Separating the traffic from the construction activity will result in increased construction efficiency. However, the increased efficiency may be minimal for activities that can be readily performed with stage construction (one lane at a time), such as cold milling or paving. Closure of a roadway on a divided highway provides the greatest advantage when the construction activity requires grading or an item that would result in temporary closure of one roadway, such as the replacement of a drainage structure.
- **Project Length**. Closing a single roadway may result in a significant reduction in the operational efficiency of the remaining roadway. The design team should consider the traffic volume, the length, and the roadway gradients of the two-way traffic because it may result in undesirable traffic congestion. The evaluation of these factors is covered in Section 10.2.2.
- **Width Restrictions.** A single roadway should not restrict the width of vehicles because of reduced lane or shoulder widths. Where it is necessary to restrict the roadway width, the design team should coordinate with the Motor Carrier Services.
- **Alternate Route Detours.** This option is generally only practical if both roadways of a divided highway are closed at the same time. However, the design team should only consider this alternative if no other option is practical. The alternate route should be a facility capable of effectively accommodating the traffic of the divided highway. The decision to use an alternate route requires a completion of the full TMP process (project worksheet and review team) and must include the evaluation and documentation of the features discussed in Section 10.2.2. Special consideration is needed for alternate routes providing multiple lanes of travel in the same direction. The driver expectancy for detour routes such as these is much greater, and higher design speeds and associated design criteria are required. The design speed of all alternate routes should be included in the plans package on all applicable detail sheets and special provisions
- **Temporary Lanes in Flush Median**. Providing temporary lanes is usually only practical where the traffic volumes would exceed the

capacity of the single roadway. The length of temporary lanes should be kept to a minimum.

10.3.5.2 Design

The following provides several design considerations where two-way traffic on a single roadway of a divided highway is used:

- **Length.** The design team should consider the length of the two-way traffic because operational efficiency is often reduced for two-way traffic on divided highways, resulting in traffic congestion. Where the DHV is less than the values shown in Exhibit 10-1, the length of two-way traffic can be extended to the limits of the project. When the DHV is greater than these values, the design team should consider installing additional crossovers to alleviate congestion. Based on MDT practice; typically, two-way traffic should be as short as practical, and lengths in excess of 4 miles should be avoided. The type of work, number and location of work zones, the roadway gradients, and the number and location of interchanges within the project should be considered when determining the number and locations of crossovers. The need for additional crossovers should ultimately be determined by the review team.
- **Positive Protection**. Positive protection is typically only provided for work zones. The design team should coordinate with the Construction Bureau, as well as the Traffic and Safety Bureau to determine the appropriate treatment in this transition area. More considerations for positive protection can be found in Section 10.5.2.
- **Roadside Safety.** The design team should consider the effect that directing traffic onto the opposing roadway will have on the roadside appurtenances. For example, existing trailing ends of unprotected bridge ends may require approach guardrail transitions or impact attenuators, and all guardrail terminals may need to be converted to an acceptable treatment. Re-lapping the existing guardrail in the opposite direction, such that each piece of W-Beam encountered by the adjacent traffic overlaps each subsequent piece of rail at the splices, is generally not required for the temporary change in direction of travel.
- **Crossovers.** Consider the following in the design of crossovers:

Temporary barrier and the excessive use of traffic control devices cannot compensate for a poor geometric design of a crossover.

  a. Tapers for lane drops should not be contiguous with the crossovers. See Section 10.4.3 for acceptable taper lengths and rates. A taper rate of 12:1 should be used for the crossover. The 12:1 taper rate is used because it is comparable to what is used for exit ramps. The crossover is similar because the driver is leaving the 4-lane facility and entering a two-lane facility. The same rate should be used for a ramp crossover.
  b. The crossover should have a design speed that is no more than 25 miles per hour below the mainline design speed before the construction zone; see Section 10.4.1. All design

speed decisions should be properly documented in the appropriate plans and reports (see Section 10.2.3).

c. The design of the crossover should accommodate the truck traffic of the roadway (e.g., surfacing widths, loads).

d. A clear recovery area should be provided adjacent to the crossover; see Section 10.5.3.

e. See the *MDT Detailed Drawings* for the geometric details of a typical crossover.

- **Interchanges.** Access to interchange ramps on freeways should be maintained even if the work space is in the lane adjacent to the ramps. If access is not practical, ramps may be closed for the shortest duration possible using proper signing for alternative ramps and detours. Early coordination with local officials having jurisdiction over the affected cross streets will be required prior to ramp closures.

  Providing access to exit and entrance ramps may require the use of additional crossovers. Sufficient deceleration and acceleration distances should be provided.

10.3.6 Work Within or Near Intersections

If the work is within or near an intersection, consider the following guidelines:

- Keep the work space small so that traffic can move around it.
- For temporary work at unsignalized intersections, maintain intersection traffic control via flaggers, temporary signals or signs.
- Coordinate with construction during the TMP meeting if staging is appropriate to maintain traffic flow and manage the work zone area. Reduce traffic volumes by detouring traffic upstream from the intersection.

Where lane shifts are used through signalized intersections, the traffic signal heads and actuated detectors will need to be re-adjusted for the temporary lane configuration. Coordinate with the Traffic and Safety Bureau for information on traffic signal designs.

10.3.7 Detours

10.3.7.1 Warrants

Detours are necessary when traffic cannot be adequately or safely maintained through the construction project on the existing roadway. Detours provide the safest method of protecting workers within the construction zone. Detours allow the contractor to work unimpeded by traffic, which will typically accelerate the project completion time. On the other hand, detours may cause inconvenience and confusion to the traveling public.

The following presents guidelines for where detours should be considered:

- Where there is a possibility of a significant hazard to traffic and/or workers.

- Where removal of traffic will substantially accelerate the project completion time.
- Where construction would be impractical if traffic was maintained (e.g., total bridge reconstruction, substantially raising fill heights).
- Where work is done at railroad crossings. (For example, this work will generally require the closing of the roadway for one to two weeks, depending on the site).

10.3.7.2 Types

Once it has been determined that a detour is necessary, consider the following detour types:

- **Existing Routes.** Detours along existing routes are generally the easiest option available. The following factors should be considered:
    a. Considerable public involvement and coordination with the affected communities and local maintaining agencies will be necessary before traffic can be detoured onto an existing route.
    b. Detours will generally require more travel time.
    c. The proposed detour route should have sufficient capacity to safely accommodate the additional traffic.
    d. Detour traffic may increase traffic delays and congestion on local roads (e.g., side streets in towns).
    e. Existing traffic signals may need to be reprogrammed or temporary traffic signals installed.
    f. Improvements may be required on the detour route to accommodate the increased road traffic (e.g., pavement resurfacing, increasing bridge loading capacities, roadside safety improvements).
    g. Ensure that structures over the alternate route provide adequate clearance and have sufficient loading for detoured traffic.
    h. The increased number/density of approaches on the alternate route may decrease the operational efficiency (especially where traffic is being detoured from a controlled access facility).
    i. Local access and approaches may still be required within the construction area.
    j. Address adequacy of the clear zone for the increased volumes.
- **Temporary Roadways**. Temporary roadways (e.g. adding lanes in the median, widening of the subgrade) are generally provided within the construction area versus detouring traffic around the area. Temporary roadways are typically constructed where:
    a. A long detour would be required,
    b. Alternate routes are impractical,

c. A heavy volume of traffic would need to be detoured,

d. Substantial improvements would need to be made to the detour route,

e. Increased truck volumes through towns would be unacceptable,

f. The detour duration would be required for a long period of time, and/or

g. Lane restrictions to create adequate work zones are impractical due to traffic volumes.

Due to the limited space available, the geometric design of temporary roadways is often much more restricted. Sections 10.4 and 10.5 provide the geometric and roadside safety criteria that should be used for temporary roadways.

The installation of drainage structures associated with temporary roadways generally requires a staged construction sequence. The preferred sequence of culvert installation should proceed from downstream to upstream. Sufficient additional culvert lengths are necessary to provide adequate lane widths and fill slopes during the installation.

- **Constructed Detours.** Constructed detours are specially constructed temporary roadways that are built within the construction zone to bypass a bridge, railroad crossing or other similar "spot" construction area. These detours are constructed where it would be impractical to detour traffic on other existing routes. The majority of constructed detours are associated with the installation of bridges and other drainage facilities.

  Design the detours using the criteria in Sections 10.4 and 10.5. However, it should be noted that they are generally more expensive, may require the purchase of construction permits, and may have adverse environmental impacts.

10.3.7.3 Location

Consider the following factors when determining detour locations:

- The detour should minimize impacts to adjacent development.
- The detour should minimize the amount and cost of utility relocations.
- The detour should minimize environmental impacts.
- Locate detours which cross watercourses downstream from the construction, where practical.
- Ensure the detour is offset a sufficient distance so as not to interfere with the construction. For bridge replacements or for existing bridges that need to be removed, attempt to provide at least 10 feet between the outside edge of the new structure or existing structure to be removed (usually the wingwalls) and the toe of the detour cut or fill slope.

Coordinate the location of detours around bridge construction sites with the Bridge Bureau.

- Evaluate the length of the detour to determine if it is cost effective to extend the detour beyond the construction zone (on short projects such as bridge replacements this decision may result in a detour that is longer than the project). It is sometimes practical that the additional cost to provide a longer detour is offset by reduced estimated traffic control costs and/or contract time.
- Coordinate the location of detours around bridge construction sites with the Bridge Bureau to ensure that adequate offset is provided.

10.3.8 Offset Alignment

For reconstructed projects, it may be cost effective to use a new alignment which is offset and generally parallel to the existing roadway. Some of the factors that should be evaluated to determine if an offset alignment may be appropriate include:

- Construction cost savings,
- Project constructability,
- Right-of-way availability and costs,
- Potential contract time reduction and road user costs,
- Existing development of adjacent property, and
- Natural features.

There are special challenges when an offset alignment is used, including the design of the connection to the existing roadway, obliteration of the existing roadway, and how to utilize material from the existing fills while maintaining traffic on the existing roadway. The effectiveness of an offset alignment may be reduced where a project involves substantial modifications to the vertical alignment. In these cases the construction limits often encompass the present travel way (PTW).

10.3.9 Urban Routes

Construction on urban routes presents their own unique set of challenges and considerations that should be discussed and coordinated as part of the TCP, TO and PI components of the TMP process. Major considerations include:

- **Pedestrian/bicycle access**. Refer to Chapter 7, Chapter 8 and the *MUTCD* for design considerations related to pedestrians and bicycles in urban environments.
- **Intensive public relations program.** Provisions need to be included in the contract to notify motorists, businesses, and residents of closures, delays and other factors that may affect them. These can include media notification and weekly meetings with city officials and local business people.
- **Utility considerations**. Replacement of storm drain, sanitary sewer and water lines often require the closure of a street to traffic. Sequencing must be addressed in detail and should be closely coordinated with District Construction.

- **Access for emergency vehicles**. Ensure that access is provided through provisions for roadway width and coordination with emergency response providers.
- **Impacts to businesses and residents.** Impacts must be minimized as much as practical. This typically requires extensive traffic control signing plans.

10.3.9.1 Detour Traffic onto an Existing Route

Detouring traffic onto other streets is fairly common for construction projects on urban routes. Closing a single block at a time in a block-by-block sequence helps to minimize disruption to local businesses and residents as well as traffic. Since sequencing is important in urban construction, the design team needs to coordinate with District Construction. In addition to the considerations listed previously in Section 10.2.2, the following items should be considered.

- **Traffic volumes.** The design team should consider if the adjacent streets handle the additional traffic volumes. Temporary signing can be used to enhance traffic movements. Converting adjacent streets to one-way traffic should also be considered.
- **Pedestrian accommodation.** The alternate routes should have pedestrian and Americans with Disabilities Act (ADA) facilities that are equivalent to those on the existing mainline. Pedestrians may still be able to use the mainline pedestrian facilities.
- **Surfacing.** The design team should consider if improvements to the surfacing are necessary. If the detour route will need surfacing treatment before placing traffic on it, provide a sequence to ensure that it happens at the appropriate time in the contract. Local authorities should be consulted if the detour route is on local routes not administered by MDT. A construction agreement with local road authorities may be needed to address detours on local roads and streets.

10.3.9.2 Lane Closures

If sufficient room is available to maintain traffic on a portion of the existing roadway, lane closures generally are the most cost effective method of detouring traffic. Considerations include:

- **Positive Separation**. Positive separation may be needed for utility installation because trenches for storm drain and sanitary sewer can present risks. *MDT Standard Specifications for Road and Bridge Construction* includes guidance regarding traffic control at drop-off areas.
- **Access to adjacent businesses and residences**. It may be necessary to use lane closures in conjunction with detouring traffic to existing routes.
- **ADA access**. Reasonable access should be provided to both sides of the roadway, where practicable.

- **Time restrictions.** Sometimes lane closures are not allowed during peak periods. The design team should coordinate with Traffic and Safety Bureau and/or District Traffic Engineers to determine if there are time restrictions for lane closures and develop TCPs based on construction methodologies for shorter construction timeframes.

10.3.10 Drainage Options

Where a detour would be required for a culvert replacement, the design team should consider the following options:

- **Jacking and Boring**. Jacking and boring a new pipe through the roadway fill may be cheaper than detouring traffic and excavating the fill to remove the existing pipe and install a new one. Since jacking a pipe is costly, it is usually only practical when pipes are located in higher fills or when a detour would be very expensive. The design team should compare the cost to the cost of a detour and new installation. Items to consider are:
    a. Size of pipe needed. Boring anything larger than a 48-inch culvert may be impractical and result in undue expense, since equipment to bore larger culverts is not readily available. The design team should verify the practical size for boring culverts as it may change over time.
    b. Constructability. A relatively level area at the bottom of the fill should be available to set up the jacking rig.
- **Pipe Inserts/Liners.** The Hydraulics Section should evaluate existing culverts to determine if an insert or liner can be installed rather than replacing the existing culvert. The feasibility of using a liner or insert will depend on the required culvert capacity and distortion in the existing culvert shape.

10.4 GEOMETRIC DESIGN

The design criteria presented in the following sections apply to temporary crossovers on divided highways, existing roadways through construction zones and detours specifically constructed for construction projects. It does not apply to detours along existing routes. While temporary facilities do not require formal design exceptions, when controlling criteria are not met, the design team should still consider the criteria and clearly document the design decisions in the appropriate plans and reports (see Section 10.2.3).

10.4.1 Design Speed

In addition to the geometric and physical considerations, the design of detours must take into account the expectations of the driver. Significant speed reductions through construction zones are undesirable and may lead to undesirable operating conditions particularly where normal traffic speeds are high. Regulatory or warning speed signs are generally ineffective with the exception, perhaps, of signs at horizontal curves. Temporary facilities should be designed with as high of a design speed as practical, considering the functional classification, traffic volumes, vehicle size and type, detour length, the number of travel lanes affected, duration, and project context. The design team should document and communicate to the construction personnel the limitations of the design, so that the detour can be managed and signed appropriately. If the limitations of the design are great enough that driver expectancy may be violated, the use of mitigation measures with sufficient deceleration distance in advance of the detour should be included to ensure safe operation. The use of mitigation measures may also be appropriate within longer detours with varying design speeds. The following factors should also be considered in the determination of a detour design speed:

- **Location**. If the detour is in the middle of a larger construction project, a lower design speed may be acceptable. The driver tends to be driving slower, or is at least more aware, because of the other construction activity that occurs prior to the detour. If a detour is part of a stand-alone bridge replacement project, the detour may be the first feature a driver encounters, and as a consequence may be approaching it at a much higher speed.
- **Duration**. The design speed should be as high as possible, particularly if the detour is going to be in place longer than three months.
- **Sight distance.** If the driver has plenty of advance warning that they are approaching a detour, a lower design speed may not violate driver expectancy. The design team must determine if the same amount of warning is provided at night.
- **Systems.** The design team needs to consider how this temporary construction condition along a specified road segment fits within the overall transportation system and/or corridor. The objective is to avoid unexpected change from a driver's expectation and the appropriate systematic messaging in the TCP should be established. Driver expectation for the Interstate system is particularly high, and design speeds for temporary facilities on the Interstate should be set accordingly.

The minimum acceptable detour design speed is 35 miles per hour for two-lane rural roadways, and 45 miles per hour when multiple lanes of directional traffic are detoured. However, if the design speed of the detour is more than 10 miles per hour less than the design speed of the mainline, the reasons for its use should be documented in the SOW Report. This also applies to the design speed of ramp detours as compared to the mainline. Detour design speeds for ramps and turning roadways should be established on the basis of a reasonable expectation that traffic will comply with a reduced construction speed zone. If physical constraints prohibit designing to the minimum speed, the circumstances should be documented in the SOW Report along with mitigating measures incorporated to ensure the safe operation of the detour.

10.4.2 Lane/Shoulder Widths

Desirably, there will be no reduction in the cross section width through the construction zone. However, this is rarely practical. For Interstates and other divided highways, at a minimum, an 11-foot lane width should be maintained through the construction zone and, preferably, with a 2-foot or wider right and left shoulder. Under restricted conditions, a 10-foot wide lane may be used if there is an alternative route provided for wide vehicles. Crossovers on divided highways must provide a 12-foot minimum lane width. For other highways, the lane and shoulder width selection should be 11 feet or wider. The design team should minimize the use of width reductions. Where necessary, Exhibit 10-2 presents the minimum taper rates that should be used when reducing widths.

Exhibit 10-2
Taper Rates for Lane Reductions

Design Speed (mph)	Taper Rate
20	10:1
25	15:1
30	20:1
35	25:1
40	30:1
45	45:1
50	50:1
55	55:1
60	60:1
70	70:1
75	75:1
80	80:1

Source: MUTCD (*2*).

10.4.3 Lane Closures/Other Transitions

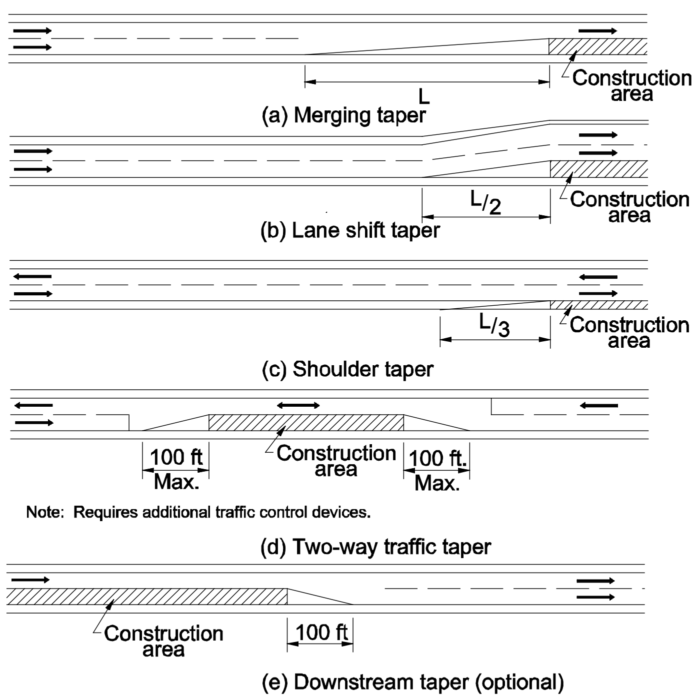
The design team should ensure that the taper rate conforms to the taper rates shown in Exhibit 10-2. Exhibit 10-3 and Exhibit 10-4 present and illustrate, respectively, the minimum taper lengths for various taper applications in construction zones (e.g., lane closures, lane shifts).

Exhibit 10-3
Taper Length Criteria for Construction Zones

TYPE OF TAPER	TAPER LENGTH
UPSTREAM TAPERS	
Merging Taper	L
Shifting Taper	1/2 L
Shoulder Taper	1/3 L
Two-way Traffic Taper	100 feet
DOWNSTREAM TAPERS (Optional)	100 feet per lane

Notes:
Length "L" determined from Exhibit 10-2.
Exhibit 10-4 illustrates the various taper types.

Exhibit 10-4
Taper Length Criteria for Construction Zones (Application)



Note: Length "L" determined from Exhibit 10-2.

10.4.4 Median Crossovers

Median crossovers built in connection with roadway construction projects on the National Highway System and Interstate Routes and left in place can be cost effective for use in construction, maintenance, and incident management.

The determination to construct median crossovers for work zone traffic control, and whether or not the crossovers will remain in place, should be discussed at the PFR. The final decision to leave the crossovers in place as a permanent installation should be made by the design team at the Plan-In-Hand and documented in the report.

Barriers and other appurtenances necessary to close the crossovers shall be installed as part of the construction project, if the median crossovers are not removed.

10.4.4.1 Plans

All details necessary to construct the median crossovers will be provided in the plans and described in the *MDT Standard Specifications* and special provisions.

10.4.4.2 Location

Crossovers should be located on horizontal and vertical tangents. Where this is impractical, crossovers should be located where adequate stopping sight distance is provided for at least the design speed of the work zone and preferably for the regular mainline posted speed of the route.

Crossovers should be located in suitable terrain, where there is minimal elevation difference between the opposing lanes. The elevation difference between the edges of median shoulders of the opposing lanes should be limited to 3 feet; however, larger elevation differences may be used where necessary depending on the median width or through modifications to a typical crossover. The *MDT Sample Plans* discussed in Chapter 12 provide additional information.

The *MDT Sample Plans* discussed in Chapter 12 provide additional information.

The crossovers should be selected so as to not interfere with maintenance turnarounds. If this cannot be accomplished, the crossovers can be modified to function as a maintenance turnaround.

Permanent crossovers generally should not be located in close proximity to urban areas and/or interchanges.

10.4.4.3 Taper Rate

A taper rate of 12:1 should be used for the crossover, because it is comparable to what is used for exit ramps. The crossover is similar because the driver is leaving the four-lane facility and entering a two-lane facility. The same taper rate should be used for a ramp crossover. Sites will be evaluated on a case-by-case basis if constraints make the use of this taper rate impractical.

10.4.4.4 Surfacing

Unless a separate recommendation is provided by the Pavement Analysis Section, the surfacing for median crossovers will consist of 0.40 feet of plant mix and 1.0 foot of crushed aggregate course. For crossovers left in place, the design team will determine if a seal and cover or fog seal is appropriate.

10.4.4.5 Drainage

The drainage features should be designed for the same frequency storm event used for the mainline (for example, the 50-year storm event). The design team will need to ensure that adequate cover is provided over the culverts. Road Approach Culvert End Treatment Section (RACETS) should be provided on all culvert ends located within the highway clear zone.

Where practical, the crossovers should be located adjacent to median drop inlets so that no other drainage facilities are needed. The crossover should typically be sloped with an inverse crown to prevent an increase in runoff across the mainline travel lanes.

10.4.4.6 Safety Considerations

Transverse slopes for temporary median crossovers should be a minimum of 10:1. Crossovers to remain permanent should be a minimum of 20:1.

The design team should evaluate the installation of crossovers on sections where two-way traffic will have to utilize bridges that only provide a 28-foot roadway width. Due to this narrow width, the increased risk could become an issue.

It is recommended that two-way traffic on one roadway of a divided highway extend for a maximum of four miles. The length between permanent crossovers needs to be evaluated on subsequent projects and in coordination with the Traffic and Safety Bureau to determine if increased traffic volumes will result in traffic queues or congestion.

10.4.4.7 Construction

The contractor will construct and maintain the crossovers in accordance with the plans and specifications, including all necessary temporary traffic control devices.

Closure

The contractor will install pre-stretched, high tension cable rail to close the crossover upon completion of construction. If a seal and cover is not placed on the crossover, the pavement markings must be removed prior to the completion of construction.

Post-Construction Maintenance

MDT Maintenance will provide normal maintenance for the crossovers. In addition, they will inspect the crossovers to ensure that delineation and other appurtenances necessary to prevent the use of the crossover are in place and in good condition. They will repair or replace signing, delineation, and guardrail, as necessary.

10.4.5 Sight Distance

Changes in the geometric design of the existing highway are often necessary through construction zones (e.g., lane shifts, detours). Therefore, the available sight distance for the approaching motorist is important. Unfortunately, the locations of many design features are often dictated by construction operations. However, some elements may have an optional location. For example, when lane closures and other transitions are specially designed, these should be located so that the approaching driver has at least the minimum stopping sight distance available to the closure or transition. Providing Decision Sight Distance is preferred. The minimum stopping sight distances are presented in Chapter 2, Section 2.8, and the *Geometric Design Standards*, and will be based on the construction zone design speed.

10.4.6 Horizontal Curvature

10.4.6.1 Minimum Radii/Superelevation

The minimum radii and superelevation of any horizontal curves will be determined using the selected design speed for the construction zone (Section 10.4.1) and based on the principles outline in Chapter 3. In construction zones, the AASHTO Method 2 for distributing superelevation and side friction may be used to determine the radius and superelevation rate of any curve. In this method, superelevation is introduced only after the maximum allowable side friction has been used. This results in eliminating superelevation on flatter curves and reducing the rate of superelevation on the majority of other curves.

The PTW width is considered the full finished top width of the existing facility, and is not just the through lanes as defined for "traveled way".

Typically, the present travel way (PTW) is widened for the detour connection using the same cross slope as exists on the PTW. Exhibit 10-5 provides the minimum horizontal curve radii for retaining normal crown, based on AASHTO Method 2, for detour connections to tangent PTW sections. Detour connections to superelevated PTW sections should be accomplished with horizontal curves requiring the same superelevation, based on AASHTO Method 2, as the in-place superelevation of the PTW. As discussed in Chapter 3, Section 3.3.7, the minimum distance between the PT and PC of reverse superelevated curves will be that needed to meet the superelevation runoff length requirements for each of the two curves.

Exhibit 10-6 illustrates a typical three-horizontal curve alignment for a minimum-length, 50-miles-per-hour, constructed detour providing approximately a 50-foot offset. The following factors should be considered when establishing a detour alignment:

- Selecting radii requiring a normal crown (NC) for curves exiting/entering tangent PTW accommodates vehicles turning onto/off the detour on the retained adverse crown of the PTW.
- Selecting radii requiring NC allows the PC and PT of successive curves to be coincident and eliminates the need for superelevation transition lengths.
- If selection of radii requiring superelevation is necessary, ensure that the proper transition lengths are provided as shown in Exhibit 10-7.
- Typical offsets between the edge of a new structure and the edge of a detour shoulder is 10 feet.
- Provide a 2-foot radius nose at the gore.

Exhibit 10-5
Minimum Radii for Horizontal Curves (Construction Zones)

Design Speed, V (mph)	f_{max} (Open-Roadway Conditions)	Min Radii, R_{min} (for Normal Section) (e = -2%) (ft)	Min Radii, R_{min} (e = 8%) (ft)
20	0.27	110	80
25	0.23	200	140
30	0.20	340	220
35	0.18	520	320
40	0.16	770	450
45	0.15	1040	590
50	0.14	1390	760
55	0.13	1840	960
60	0.12	2400	1200
65	0.11	3130	1480
70	0.10	4090	1810

Notes:

1. **Curve Radii**. Radii are calculated from the following equations:

   $R = \frac{V^2}{15(e+f)}$ values for design have been rounded up to the next highest 10-foot increment.

2. **Normal Section**. If the normal section is maintained through the horizontal curve, the superelevation rate is -0.02 assuming a typical cross slope of 2%. Therefore, the R_{min} column with e = -2% presents the minimum radii which can be used and retain the normal section through the horizontal curve.

3. **Other Radii.** For proposed radii or superelevation rates intermediate between the table values, the equation in Note #1 (Curve Radii) may be used to determine the proper curvature layout. For example, if the construction zone design speed is 60 mph and the proposed curve radius is 1,640 feet, then the superelevation rate is:

$$e = \frac{V^2}{15R} - f$$

$$e = \frac{(60)^2}{(15)(1640)} - 0.12$$

$e = +2.6\%$, round to +3.0%

(Round the calculated superelevation rate to the next highest percent).

**Exhibit 10-6
Typical Detour Alignment
(Maintaining Normal Crown
Section) (Design Speed: 50
mph)**

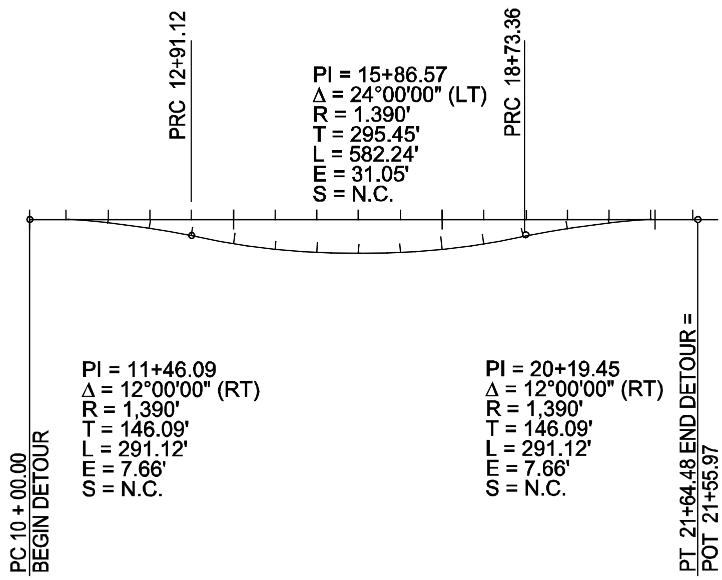
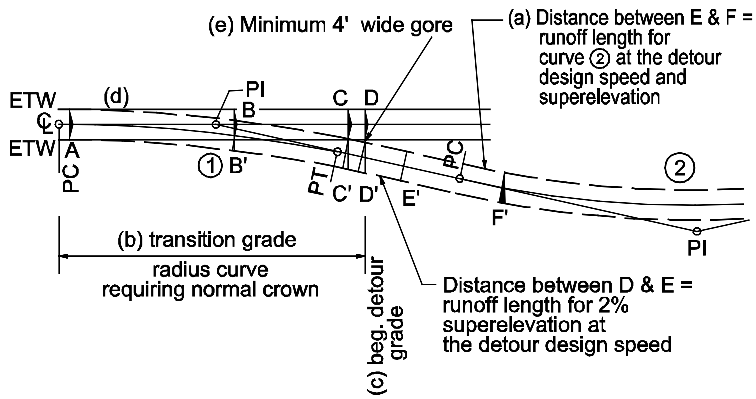
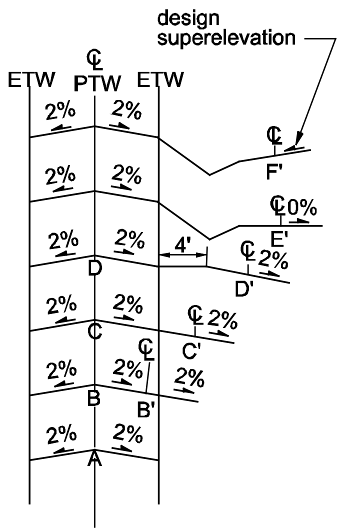


Exhibit 10-7 Horizontal Curves for Detours (With Superelevation)





(a) This applies if Curve 2 is superelevated. If Curve 2 is flat enough to retain the normal crown, the PT of Curve 1 and PC of Curve 2 can be coincident. Transitioning the 2% cross slope at Section D' to normal crown can then be accomplished within Curve 2.

(b) Throughout the transition grade, detour centerline elevations are computed by multiplying the offset distance and the cross slope between the centerlines. This distance is then subtracted from the mainline centerline elevation.

(c) Independent detour grade begins at the point of full separation between mainline and detour (Section D').

(d) Detour connections to a curved present traveled way (PTW) alignment should be accomplished with a horizontal curve requiring the same superelevation, based on Exhibit 10-6, as the in-place superelevation of the PTW.

(e) This distance is typically added to the shoulder widths of the mainline and detour (if they have them) and not measured between edges of the traveled way as shown. The gore nose typically matches the cross slope of the mainline or provides a shallow ditch profile for drainage.

10.4.6.2 Transition Lengths

Chapter 3, Section 3.3.4 presents MDT criteria for superelevation transition lengths for permanent construction projects. These lengths will be provided for detours in construction zones and are based on detour design speed. Note that superelevation is transitioned throughout the detour using a continuously rotating plane in Exhibit 10-7.

Chapter 3 provides information for determining transition length for two-lane, two-way roadways in rural conditions, multilane roadways in rural conditions, and roadways in urban conditions.

10.4.7 Vertical Alignment

A transition grade should be used for the detour alignment from the beginning/end of the detour to the gore. An independent grade should be designed between the gores.

Throughout the transition grade area, detour centerline elevations are computed from the PTW profile and cross slope, similar to transition grades for ramps or other turning roadways. Additional information on transition grades for detours is provided in Chapter 4, Section 4.2.6.

If a detour crosses a water feature, ensure that the detour grade provides minimum cover for all culvert options to accommodate the waterway opening or the elevation required for placement of the temporary bridge.

Vertical curve criteria presented in Chapter 4 is also applicable to detours.

10.4.8 Surfacing

All detours for Interstate projects will be paved. Detours for projects on other routes may have paved, treated or gravel surfaces. Factors that influence the type of surfacing used for these detours include:

- The Average Daily Traffic (ADT) on the route (routes with higher ADT's require more durable surfacing),
- The length of time the detour will be in use,
- The anticipated detour posted speed, and
- The maintenance that would be required for the various types of surfacing. The ADT will also affect the level of maintenance.

See Exhibit 10-8 for general guidance as to the type of surfacing for detours.

Exhibit 10-8
Guidelines for Selection of Detour Surfacing

Current ADT	Duration of Detour Operation			
	< 5 Days	5 - 30 Days	31 Days - 3 Months	> 3 Months
< 500	Gravel	Gravel	Treated Gravel	Treated Gravel
500 - 1499	Gravel	Treated Gravel	Treated Gravel	Plant Mix Surfacing (PMS)
1500 - 6000	Treated Gravel	Treated Gravel	PMS	PMS
> 6000	Treated Gravel	PMS	PMS	PMS

Notes:
Gravel is untreated crushed aggregate course (CAC).
Treated gravel is CAC that has an aggregate treatment applied to the riding surface to help control dust and add durability.
Plant Mix Surfacing (PMS) is a paved surface on top of a CAC base.

10.4.9 Cut and Fill Slopes

Wherever practical, construct detour cut and fill slopes according to the *MDT Geometric Design Standards* and Chapter 9 *(3)*. The use of 3:1 fill slopes is acceptable where a sufficient clear zone is available at the bottom of the slope. The use of steeper fill slopes may require the installation of barriers.

Although detours rarely involve excavation (cut), 3:1 cut slopes are generally acceptable in place of the 5:1 and 4:1 slopes described in the *Geometric Design Standards* and Chapter 9 (*3*). The use of slopes steeper than 3:1 for cut depths less than 10 feet should be reviewed at the Plan-in-Hand.

The anticipated traffic volumes, design speed of the detour and the length of time the detour will be in place should be weighed in determining cut and fill slopes.

10.4.10 Temporary Pavement Markings

Temporary pavement markings provide guidance for roadway users traveling through the construction area. Additionally, temporary pavement markings may be required:

- After milling operations (if traffic will be driving on the milled surface), and
- Between each pavement lift.

They may also be required on existing pavement, which may require the removal of permanent pavement markings to eliminate conflicting messaging. Chapter 13 presents the procedures for estimating quantities.

10.5 ROADSIDE SAFETY

As drivers traverse construction zones, they are often exposed to numerous challenges including restrictive geometrics, construction equipment and opposing traffic. Elimination of these restrictions is often impractical. Regardless, consideration must be given to reducing the exposure of motorists to risks.

10.5.1 Positive Protection

During the planning and design of a project, give careful consideration to traffic control plan alternatives that do not require the use of temporary barriers. This can often be accomplished by using detours, constructing temporary roadways, minimizing exposure time, and maximizing the separation between traffic and workers. Even with proper project planning and design, there will still be instances where positive protection should be considered.

Because each site should be designed individually, MDT has no specific warrants for providing positive protection in construction zones. The design team should coordinate with the Construction Bureau and field construction personnel to make the determination whether to provide positive protection in construction zones and capture the decision in the TCP. The *MDT Standard Specifications for Road and Bridge Construction* can be used as a reference to assist in the decision process. The following provides a list of factors that should be considered:

- Duration of construction activity,
- Clear zone for the construction zone design speed,
- Traffic volumes (including seasonal fluctuations),
- Nature of potential conflict,
- Design speed,
- Highway functional class,
- Length of hazard,
- Proximity between traffic and construction workers – consider dynamic deflection of barrier,
- Proximity between traffic and construction equipment,
- Adverse geometrics which may increase the likelihood of run-off-the-road vehicles,
- Two-way traffic on one roadway of a divided highway, and
- Transition areas at crossovers, and/or lane closures or lane transitions.

10.5.2 Appurtenance Types

The first objective should be to provide a design that eliminates the need for temporary barriers. However, this is often not practical. In addition to Chapter 9 and the *MDT Detailed Drawings*, the following provides general information on the roadside safety appurtenances used by MDT through construction zones:

- **Guardrail/Barrier Rail.** For most construction projects, the installation of a new temporary guardrail/barrier rail is usually not cost effective due to the short project life. Where used, temporary guardrail/barrier rail installations must meet the permanent installation criteria set forth in Chapter 9 and the MDT Detailed Drawings, except where modified in Section 10.5.3.
- **Temporary Concrete Barrier Rail (TCBR)**. The most common type of portable barrier is a TCBR. A TCBR provides the greatest protection from the construction zone and between two-way traffic, but it is also the least forgiving to the driver. The primary functions of the TCBR in construction zones are:
    a. To keep traffic from entering work areas (e.g., excavations, material storage sites);
    b. To protect workers and pedestrians;
    c. To separate two-way traffic;
    d. To shield obstacles and edges; and
    e. To protect construction such as falsework for bridges and other exposed objects.

The design team should consider the horizontal clearance if TCBRs are installed along both sides of the temporary roadway to accommodate oversized/overweight heavy vehicles.

To determine the appropriate temporary barrier placement, the site should be classified as high or lower risk. A high risk situation is defined as a situation in which a barrier placement that exceeds the design deflection will likely result in death or injury. (An example would be a vertical drop off along the edge of Phase 1 on a phased bridge construction project.)

High Risk Sites

For high risk sites, anchor (pin down) the temporary barrier as shown in the Detailed Drawings.

Lower Risk Sites

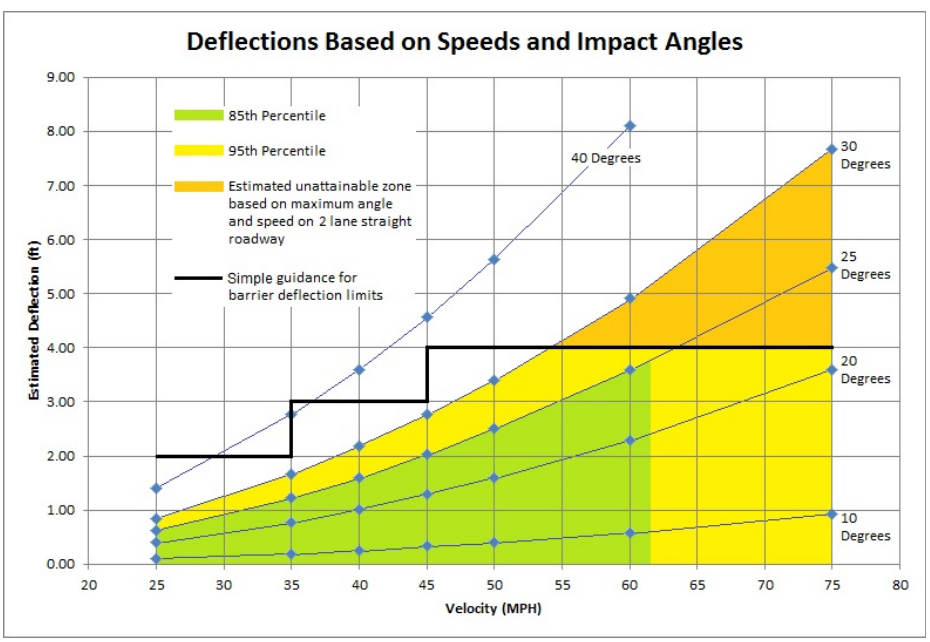
For lower risk sites with straight roadways and with a single lane or two lanes in the same direction, a simple approach is to pin down the barrier, if there is not sufficient space to accommodate the minimum deflection limit. The minimum deflection limit is shown in Exhibit 10-9.

Exhibit 10-9 Minimum Deflection Limits

Speed (mph)	Deflection (ft)
Less than 35 mph	2
35 - 44 mph	3
45 mph or greater	4

The minimum deflection limit shown in Exhibit 10-9 is conservative for many applications. Exhibit 10-10 provides a more refined estimate of deflection for curved roadways, or for three-lane or larger roadways. The speed and impact angle can be used to determine deflection, or alternatively, available deflection and impact angle can be used to determine the appropriate speed limit.

Exhibit 10-10 Deflections Based on Speeds and Impact Angles



Source: MDT, 2015 (4).

Each site will require consideration of all factors to develop a site-specific deflection limit. The list of factors that should be considered and used to adjust the indicated deflection limit as appropriate is in Section 10.5.1.

The decision on where to use a TCBR in construction zones will be determined on a site-by-site basis. The design team needs to coordinate with District Construction to determine the extent of the TCBR and how many times it will be reset.

- **End Treatments.** Even when protected or otherwise mitigated, the ends are the most hazardous element of any barrier system. Therefore, any unprotected terminal ends for guardrail or the TCBR should be located as far as practical from the roadway (outside the clear zone) or be protected with an appropriate end treatment.

The end treatment to protect the blunt end of the CBR should be selected to best fit the project context and should be properly documented in the appropriate plans and reports (see Section 10.2.3).

Chapter 9 provides information on other end treatments used by MDT. Provide the safest end treatment consistent with cost effectiveness and geometric considerations.

10.5.3 Design/Layout

In general, when designing and laying out temporary roadside safety appurtenances in construction zones, use the criteria set forth in Chapter 9. However, due to the limited time exposure, it may not always be cost effective to meet the permanent installation criteria. The following provides several alternatives the design team may use in designing and laying out temporary roadside safety appurtenances:

- **Clear Zones.** Applying the clear zone distances for new construction/reconstruction, as presented in Chapter 9, to construction zones is often impractical. MDT has developed revised distances for clear zones through construction zones, which are presented in Exhibit 10-11. Due to the hazardous conditions which typically exist in construction zones, the design team still should use considerable judgment when applying these clear zone distances. Note that it is not necessary to adjust the construction clear zones in Exhibit 10-11 for horizontal curvature.
- **Length of Need.** As with new installations, provide a sufficient distance of a full-strength barrier prior to the hazard to minimize the potential for a vehicle to run behind the barrier and impact the hazard. For temporary layouts, determine the length of need by using an angle of 15 degrees from the back of the hazard or from the clear zone distance off of the edge of traveled way.
- **Shoulder Widening.** When a temporary barrier is placed next to the shoulder, it is not necessary to provide the extra 2 feet of shoulder widening.

- **Flare Rates.** Desirably, the CBR terminus should be flared away from the traveled way to a point outside of the clear zone. Exhibit 10-12 presents the desirable flare rates for the CBR based on the design speed in construction zones. The design team should provide these flare rates unless under extenuating circumstances it is impractical to do so (e.g., stop conditions, driveways, intersections).
- **Departure Angle.** As discussed in Chapter 9, based on a number of field studies, the 80^{th} percentile angle of departure is estimated to be 15 degrees. These flat angles of departure result in the need to extend the barrier a distance in front of the obstacle, which determine the length of need. More information is provided in Chapter 9.

**Exhibit 10-11
Clear Zone Distances (ft) (Construction Zones)**

All distances are measured from the edge of the traveled way (ETW).

For clear zones, the ADT will be the total current ADT for both two-way roadways and one-way roadways.

Detour Design Speed	ADT	Fill Slopes 6:1 or Flatter	5:1	4:1	3:1
35 mph or less	< 750	3	5	5	See Procedure in Section 9.2.2.
	750-1499	5	6	8	
	1500-6000	6	7	8	
	> 6000	8	8	10	
45 mph	< 750	5	6	7	
	750-1499	6	8	10	
	1500-6000	8	10	12	
	> 6000	10	12	13	
50 mph	< 750	6	6	8	
	750-1499	8	10	10	
	1500-6000	10	12	13	
	> 6000	12	13	15	
55 mph	< 750	6	8	10	
	750-1499	8	10	12	
	1500-6000	10	13	15	
	> 6000	11	13	16	
60 mph	< 750	8	10	12	
	750-1499	10	13	16	
	1500-6000	13	16	20	
	> 6000	15	18	23	
70 mph	< 750	10	12	14	
	750-1499	12	15	18	
	1500-6000	15	18	21	
	> 6000	16	20	23	

Notes:
See Section 9.2.2.3 for application of clear zones in cut sections.

Detour Design Speed	Flare Rates
45 mph or less	9:1
50 mph	11:1
55 mph or greater	13:1

Exhibit 10-12
Flare Rates for Temporary Concrete Barrier Rail

10.6 DRAINAGE STRUCTURES

The Hydraulics Section will determine the type of temporary drainage structures that are required for detours or crossovers. If a bridge will be needed, the Hydraulics Section will provide the dimensions for the waterway opening.

10.6.1 Perennial (Active) Streams

The design team should coordinate with the District Biologist early in the detour design process to determine the treatment that should be used in conjunction with the culvert installation and to address other environmental challenges associated with the detour. Prior to installing the detour culvert in a perennial stream or a stream with a high resource value, one of the following treatments will be required.

- Place drain aggregate in the channel bottom extending 2 feet beyond each side of the active channel. The drain aggregate should be placed to an average depth of 6 inches for the entire length of the culvert. (drain aggregate is defined in the *Standard Specifications*). This treatment is typically preferred for use in perennial streams. Or,
- Place erosion control geotextile in the active channel. The geotextile should extend 2 feet beyond each side of the active channel for the entire length of the culvert.

Geotextile must also be placed on the upstream and downstream face of the detour embankment. The geotextile should be keyed into the toe of the fill and the top of the fill. It should extend at least 3 feet beyond the defined channel banks. Note that the defined channel banks may not be the same as the active channel.

10.6.2 Intermittent & Ephemeral Streams

The following treatment should be used for intermittent or ephemeral streams.

- Place drain aggregate or hay/straw in the channel bottom extending 2 feet beyond each side of the low water channel. The drain aggregate, hay, or straw should be placed to an average depth of 6 inches for the entire length of the culvert (drain aggregate will meet the requirements in the *Standard Specifications*).
- If wetlands or riparian areas are impacted by the detour embankment outside of the banks of any stream, geotextile, drain aggregate or hay or straw should still be placed over the affected wetlands or riparian

areas to delineate the original ground elevation (i.e., the treatment will be placed the entire width and length of the base of detour embankment through wetland/riparian areas).

10.7 REFERENCES

1. Montana Department of Transportation (MDT). *Work Zone Safety and Mobility (WZSM).* MDT, Helena, MT, 2015.
2. Federal Highway Administration (FHWA). *Manual on Uniform Traffic Control Devices (MUTCD)*. FHWA, Washington, D.C., 2009.
3. Montana Department of Transportation (MDT). *Geometric Design Standards.* MDT, Helena, MT, 2016.
4. Construction Engineering Services Bureau. *Research Report for Temporary Concrete Barrier Deflections*. MDT, Helena, MT, August 25, 2014. (rev. February 18, 2015).

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 11

Drainage and Irrigation Design

December 2023

Contents

Chapter 11

Drainage and Irrigation Design

Chapter 11 presents principles and criteria for the design and consideration of drainage facilities in collaboration with the roadway design; including:

- culverts,
- special-purpose large culverts,
- storm drains,
- roadside drainage,
- miscellaneous drainage facilities,
- irrigation facilities, and
- encasement pipes.

For detailed hydraulic design methods and policies, the *MDT Hydraulics Manual* is available at the following link on the MDT website and should be referenced in conjunction with the information in this chapter.

[MDT Hydraulics Manual]

The MDT Permanent Erosion and Sediment Control (PESC) Design Guidelines should also be referenced for an understanding of erosion control measures required with the design and implementation of drainage facilities. This manual is available at the following link on the MDT website.

The *MDT Permanent Erosion and Sediment Control Best Management Practices Manual* provides additional information on erosion control, primarily with regard to temporary conditions.

[MDT Permanent Erosion and Sediment Control (PESC) Design Guidelines]

Drainage design details are provided in the *MDT Detailed Drawings*, which are provided at the following link on the MDT website:

[MDT Detailed Drawings]

11.1 DESIGN PRINCIPLES AND APPROACH

Extensive coordination with the MDT Hydraulics Section should occur throughout the drainage design process.

Drainage facilities carry water across the right-of-way and remove stormwater from the roadway. Drainage facilities include bridges, culverts, channels, curbs, gutters, inlets, and various types of drains.

Drainage design is an integral component in the design of roadways and must be closely coordinated with other roadway design elements. There are many aspects that fall under the general category of drainage design. This chapter focuses heavily on design requirements and considerations in relation to culverts but also addresses a number of other drainage topics to be accounted for by the design team.

Live loads are the weight of an object (most commonly a vehicle) passing over a pipe. Earth loads are the weight of the material resting on top of the pipe.

Pipes may be fabricated out of many different types of material, and each of these materials presents different structural properties in response to both live loads and earth loads. The hydraulics designer will provide information for the different pipe material options, including wall thickness, size of corrugations, and class of concrete for all culverts. It is MDT's practice to specify alternate or optional pipe materials where they can be used, with the basic bid item for optional pipe being steel.

Stormwater collection and conveyance occurs primarily through the use of storm drains and roadside drainage facilities. The detailed design of storm drains is prepared by the hydraulics designer. However, the design team is responsible for calculating the quantity of trunk line, granular bedding, and length of lateral lines and for checking for adequate cover over storm drain facilities. The storm drain design is an iterative process between Roadway Design Section and the hydraulics designer to establish a storm drain system that functions with the road grades, cross slopes, flow lines, and American with Disabilities Act (ADA) features.

For roadside drainage, the design team must ensure roadside drainage features are designed and constructed with consideration to the potential consequences of run-off-the-road vehicles. Refer to Chapter 9, Section 9.3.5 for detailed discussion on the design and safety considerations of roadside drainage features. Skewed pipes require special attention as the inside corners have the potential to be a roadside hazard.

Irrigation facilities must also be considered in the roadway design. Whenever possible, the design team should strive to locate longitudinal irrigation ditches outside of the right-of-way. The design team must coordinate with the hydraulics designer for all design details related to irrigation facilities.

This chapter also discusses several special-purpose large culverts and miscellaneous drainage features used for certain drainage design situations such as vehicular underpasses, stockpasses, and wildlife crossings. Additionally, coordination with the hydraulics designer may be required for special designs such as ditch blocks, interceptor ditches and dikes, streambank protection, detention basins, and retention basins.

11.2 CULVERTS

Nearly all drainage and irrigation facilities involve the use of some type of culvert. Culvert design requires a determination of:

- pipe material,
- design service life,
- pipe size and shape,
- pipe length,

- structural and installation requirements,
- pipe end treatments,
- pipe inlet and outlet edge protection, and
- pipe bedding/foundation.

11.2.1 Pipe Material

Pipes may be fabricated from concrete, steel, smooth steel casing (jacked and bored), aluminum, or plastic material. Pipe material selection will be based on an evaluation of the project location's soil and water corrosive characteristics. The hydraulics designer will provide recommendations for the different pipe material options including wall thickness, size of corrugations, coating, and class of concrete for all culverts.

11.2.1.1 Common Pipe Materials

The pipe materials listed in Exhibit 11-1 are commonly used by MDT. Pipe material selection for mainline culvert crossings, approach culverts, irrigation facilities, and storm drains is based on design criteria such as service life, site conditions, and its intended use. The pipe materials in Exhibit 11-1 are not intended to be all inclusive; therefore, a proper engineering analysis is required for all installations. For large installations, the analysis should include installation cost comparisons.

Exhibit 11-1
Pipe Materials

Pipe Material	Abbreviation	MDT Specification
Corrugated Steel Pipe*	CSP	709.02
Corrugated Steel Pipe Arch*	CSPA	709.02
Structural Steel Plate Pipe	SSPP	709.03
Structural Steel Plate Pipe Arch	SSPPA	709.03
Reinforced Concrete Pipe	RCP	708.01.2
Reinforced Concrete Pipe Arch	RCPA	708.01.3
Reinforced Concrete Box	RCB	Standard Special Provision 603-3
Corrugated Aluminum Pipe	CAP	709.07
Steel Casing Pipe	SCP	709.01.2 & Special Provision 603-1
Corrugated Polyethylene Pipe	HDPE	708.07
Solid Wall Polyethylene Pipe	HDPE	708.08.2
Large Diameter PVC Pipe (18”-48”)	PVC	708.05.3
Profile Wall PVC Pipe (4”–36”)	PVC	708.05.4
PSM PVC Pipe (15” or Less)	PVC	708.05.2
PVC Pressurized Pipe	PVC	708.06

* Acceptable coatings:	-Type II Aluminized	AASHTO M274	MDT 709.12
	-Pre-Coated Polymeric	AASHTO M245	MDT 709.05

For reconstruction projects where existing pipes can be used in place and require lengthening, the additional length of pipe usually will be constructed of the same material as the existing pipe. Pipes to be lengthened will be identified in the hydraulics designer recommendations.

11.2.1.2 Optional Pipe Materials (Basic Bid Item)

The hydraulic engineer determines which pipe materials are acceptable for each project based on service life, fill height, etc. The acceptable pipe materials are shown in the plans as optional pipe. During construction, the contractor may select which option to use.

The basic bid item for optional pipe is steel. If steel pipe is not an option in the design, then reinforced concrete pipe (RCP) will be the basic bid item. Only the basic bid items are shown in the plans and cross sections. The allowable optional pipe materials for the project are listed in the culvert summary frame.

11.2.1.3 Alternative/Optional Pipe Materials

Alternate bids will be used when the area of the opening is greater than a 10-ft diameter round pipe and the use of both materials is appropriate. Alternate bids can be provided for small structures if the design team elects to do so. All alternate bid items are shown in the plans, summaries, and cross sections. The hydraulic engineer will determine and document which materials are appropriate for a project.

11.2.2 Design Service Life

The hydraulics designer will use service life criteria in the Hydraulics Manual to determine the allowable pipe materials and the required wall thickness, type of coating, and any special requirements for new pipes.

For specific design service life criteria, see Section 11.6 of the MDT Hydraulics Manual "Pipe Material Selection & Structural Requirements".

11.2.3 Pipe Size

The minimum pipe size for new mainline drainage pipes is 24" in diameter. The minimum pipe size for irrigation pipes is 18" in diameter. Equivalent arch pipes may be used. If an approach pipe also carries irrigation water the hydraulics designer will determine the appropriate pipe size.

Pipes located underneath public road approaches must be at least 24" in diameter, while pipes located underneath private approaches and farm field approaches must be at least 18" in diameter. The hydraulics designer will provide the pipe sizes for approach culverts that convey significant flows, and the road design team will provide approach pipes at all other locations where necessary.

Locate the entire road approach pipe, including the end treatments, outside the clear zone where practical. Flared End Treatment Sections (FETS) will be provided for all approach culverts located outside the clear zone. Where it is not practical to place approach culverts outside the clear zone, specify the 6:1 Road Approach Culvert End Treatment Section (RACETS).

Occasionally, pipes may need to be oversized to account for environmental needs such as Aquatic Organism Passage (AOP), wildlife, or stock crossings based on the specific location. See Section 11.3 for discussion on special-purpose large culverts.

The hydraulics designer will provide pipe size and material type recommendations for all mainline drainage and irrigation crossings. The design team will design all culvert inlet, outlet ditches, and ensure roadside ditches maintain positive drainage. The design team should keep in mind that many pipes, especially larger diameter pipes, are typically embedded below the flowline.

11.2.4 Pipe Length

FETS = Flared End Terminal Section

RACETS = Road Approach Culvert End Treatment Section

Safety End Section = Used on mainline culverts greater than 30” in diameter that cannot be extended beyond the clear zone.

The design team determines pipe length by measuring along the pipe flowline and including any end treatments. If the pipe installation is perpendicular or skewed less than 5 degrees to the roadway centerline, then the pipe length may be scaled directly from the roadway cross section. If the pipe is skewed more than 5 degrees, scale its length along the skewed line.

When end sections are specified (such as FETS, RACETS, step bevel or beveled ends), measure the pipe length, including the end sections, along the pipe flowline. Additional pipe length is not required for the end sections. However, if the end treatment is square to the skewed pipe, the pipe must be extended beyond the toe of the slope, and additional pipe length is required to ensure the fill slope catches at the inside corner of the concrete edge protection. Chapter 13 provides additional information on measuring and quantifying pipe lengths.

11.2.5 Structural Requirements for Pipes

Fill Height Tables are located in MDT Hydraulics Manual Chapter 11, Appendix A.

Pipes have different structural capabilities depending on the pipe size, both in terms of diameter and material thickness. In general, the smaller diameter the pipe and/or the thicker the pipe material the more load the pipe can withstand. The design team must be aware of these properties to ensure the fill heights fall within the maximum and minimum allowable ranges for the pipe material and size specified. See Section 11.6.3 of the MDT Hydraulics Manual for information on measuring fill heights and structural features of pipe material types.

11.2.6 Multiple Pipe Installations

It may be necessary to install two or more adjacent culverts at one location to provide adequate conveyance. Multiple pipe installations are identified as a "double" or a "triple" installation at the station representing the center of the installation. Typically, a single pipe crossing is preferred to multiple pipe installations.

The hydraulic designer will specify the spacing between culverts and the detail for the plans.

11.2.7 Culvert End Treatments

See the *MDT Detailed Drawings* for the standard culvert end treatments.

Pipe end treatments exist along the roadside and may result in a roadside hazard if not properly located and designed. The proper type of end treatment varies depending on the pipe size, shape, material, and orientation to the roadway. Inlet and outlet protection may also be specified at pipe ends to prevent erosion and maintain the integrity of the pipe and roadway.

Exhibit 11-2 provides criteria for determining the proper end treatments for cross drain structures based upon pipe type and size. These end treatment criteria apply to both single- and multiple-pipe installations. Refer to Chapter 9 of the Road Design Manual and Chapter 11 of the Hydraulics Manual for detailed information on the proper use and installation of culvert end treatments in relation to roadside safety best practices.

Exhibit 11-2
Culvert End Treatment Determination

Pipe Type and Size	End Treatment	Cutoff Walls	Inlet/Outlet Concrete Edge Protection
RCP ≤ 48"	FETS	No	No
RCP ≥ 54"	FETS	Yes	No
RCPA ≥ 65" x 40"	FETS	Yes	No
CMP ≤ 48"	FETS	No	No
CMP ≥ 54"	Step Bevel①	Yes	Yes
CSPA or SSPPA ≥ 54"	Bevel①	Yes	Yes
SCP ≤ 48"	FETS	No	No
SCP ≥ 54"	Square	Yes	Yes

CMP = Corrugated Metal Pipe (CSP or CAP)

FETS = Flared End Terminal Section

Notes:

① Type of bevel will be identified on the plans and culvert summary frame (e.g., 2:1 step bevel, 2:1 bevel).

② In special situations, square ends may be specified by the hydraulics designer. For square ends on culverts ≤ 48" or equivalent, the culvert length should be extended 2 feet beyond the toe of the fill slope. For square ends on culverts ≥ 54" or equivalent, add cutoff walls and concrete edge protection to the inlet and outlet.

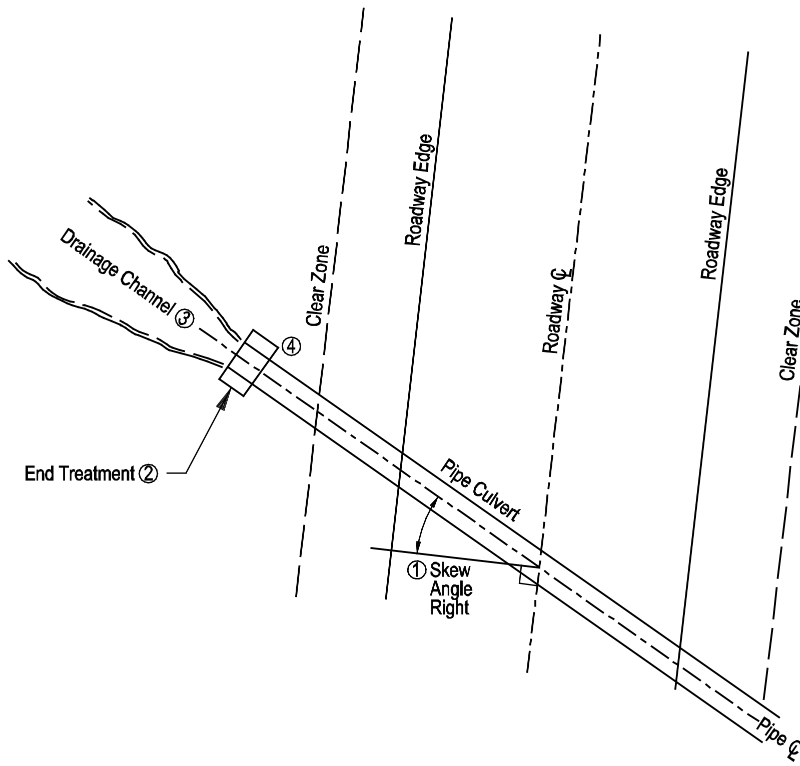
11.2.7.1 Skewed Pipe Installations

Concrete pipes are not beveled or skew-beveled.

The skew is defined as the angle measured left or right from a line which is perpendicular to the roadway centerline. See Exhibit 11-3 for a general illustration of pipe skew in relation to the roadway orientation.

See Section 11.4.6.1 of the MDT Hydraulics Manual for additional information on pipe skew.

Exhibit 11-3
Pipe Skew



① A skew angle right is one where the pipe centerline is to the right of a line extended perpendicular from the roadway centerline. A skew angle left is one where the pipe centerline is to the left of a line extended perpendicular from the roadway centerline.

Avoid skew angles greater than 35 degrees.

② End treatments for all single concrete pipe and corrugated steel pipe installations with diameters 48” or less will be installed perpendicular to the centerline of the pipe regardless of pipe skew, unless specified otherwise by the hydraulics designer.

The following will apply to installations of corrugated steel and structural steel plate pipe diameters 54” or greater:

- For skew angles 0° to 15°, the end treatment should be perpendicular to the centerline of the pipe.
- For skew angles 16° to 35° and fill height 10 feet or less, the end treatment should generally be skew-beveled. The design team should verify this with the hydraulics designer.
- For skew angles 16° to 35° and fill height greater than 10 feet, the end treatment should generally be perpendicular to the centerline of the pipe and the fill warped to the pipe ends. The design team should verify this with the hydraulics designer.
- Avoid skew angles greater than 15° for structural steel plate pipe culverts.

③ Consider channel realignment changes where appropriate, with consideration of potential environmental impacts, to limit pipe skew.

④ The pipe should be extended so that the near corner of the edge protection catches the fill slope beyond the clear zone.

11.2.7.2 Inlet and Outlet Edge Protection

The hydraulic characteristics of some drainage channels may require special protection for the roadway embankment at the inlets and outlets of pipe installations. The hydraulics designer will provide design information for special features.

If skew-bevels are used, concrete edge protection is required to strengthen the top arch on the pipe inlet and outlet. Bolting should follow the *MDT Detailed Drawings*.

If a culvert requiring edge protection is skewed, the design team should design the edge protection to match the roadway inslope and extend the culvert sufficiently to be adequately protected by the edge treatment.

For metal pipes 48″ or less in diameter, it is not necessary to provide special protection unless the hydraulics designer provides specific recommendations to do so. For metal pipes 54″ or larger in diameter, provide the protective measures described in the *MDT Detailed Drawings*, as applicable:

- Cutoff walls at both ends, and
- Concrete edge protection at inlet and outlet.

See the *MDT Detailed Drawings* and *MDT Hydraulics Standard Drawings* for estimated quantities for cutoff walls and inlet and outlet edge protection.

Concrete pipes 54″ or larger in diameter with FETS require cutoff walls at both ends. Concrete edge protection should not be used unless specified by the hydraulics designer. Riprap edge protection should not be used in conjunction with the standard end treatment for concrete pipe unless specified by the hydraulics designer.

11.2.8 Pipe Bedding/Foundation

Bedding is required for all pipe installations per the *MDT Detailed Drawings*. For pipes 48″ in diameter or less, bedding is paid for within the cost of the pipe and does not need to be shown in the culvert summary. For pipes 54″ or larger in diameter, granular bedding must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

When foundation material is specified, it will be placed below the granular bedding or bedding material. Foundation material must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

11.2.9 Riprap

The hydraulics designer will typically design embankment protection, outlet aprons, and other features requiring riprap. The hydraulics designer will work with the design team to calculate quantities and provide the necessary details. Show the riprap on the plans and cross sections and include the quantities in the appropriate summary.

The layout and quantities of riprap at bridge ends will be coordinated between the design team, the hydraulics designer, and the Bridge Bureau. Riprap will be shown on both the plan and profile, and the quantities will be included in the appropriate summary. Riprap details may need to be included in the plan set. Geotextile will be provided with all riprap installations unless otherwise specified.

11.2.10 Metal Culvert Extensions

Re-lay means to reinstall the existing culvert end treatment rather than installing a new end treatment.

The following will apply for metal culvert extensions:

- The hydraulics designer will evaluate the remaining service life of the pipe to determine if it should be extended or replaced. This determination is generally based on the condition of the in-place pipes.
- The length of extension includes the new end treatment section, unless the existing section will be removed and re-laid. Note this in the culvert summary.
- The design team is responsible for determining the length of pipe extensions. The hydraulics designer may recommend new end treatments on a case-by-case basis.
- If the existing pipe is a metric size, the diameter will be converted to US Customary units and rounded to the nearest inch (e.g., 600mm = 24 inches). The pipe extensions will be called out using the available US Customary size for the pipe.
- The thickness of the extension pipe should match the existing pipe thickness (e.g., a 0.064″ thick pipe extension should not be connected to an existing pipe that is 0.079″ thick).
- When the material or configuration of the existing pipe cannot be matched, a concrete collar will be needed to connect the extension to the existing pipe. Metal bands can be used to connect CSP to SSPP where the connection is beyond the edge of the surfacing section. This connection will require a special detail, and a CSP Verification special provision will typically be included, requiring the contractor to verify the existing CSP pipe dimensions prior to lengthening.
- Fill height for pipe extensions will be measured at the point of connection to the existing pipe unless otherwise specified.

11.2.11 Reinforced Concrete Pipe Extensions

The required minimum length of extension for reinforced concrete pipe is as follows (length is measured from the end of the existing pipe barrel minus the existing end treatment or any damaged pipe sections.):

- Diameter ≤ 30″: 10 feet, including 4 feet of new pipe and a 6-foot standard terminal section.
- 30″ < Diameter ≤ 72″: 12 feet, including 4 feet of new pipe and an 8-foot standard terminal section.
- Diameter > 72″: Contact the hydraulics designer.

- If extension of the barrel is not required, a FETS can be added without any additional length of pipe.
- Fill height for pipe extensions should be measured at the point of connection to the existing pipe.
- Connection to the existing RCP pipe can be made by matching the existing RCP joint, utilizing an RCP Adapter Ring in accordance with the *MDT Detailed Drawings,* or a Field Cast Concrete Connection in accordance with the *MDT Detailed Drawings*.

11.2.12 Culvert Cleaning

These guidelines on culvert cleaning apply only to projects involving Federal-aid funds.

It may be desirable to include cleaning of existing culverts with design projects. The following guidelines should be followed to determine and document whether a culvert is eligible for cleaning on projects involving Federal-aid funds:

- Except in special cases, such as difficult to reach culverts, only culverts larger than 48″ are eligible to be cleaned with Federal-aid funds. All culverts larger than 48″ will be evaluated for cleaning on a case-by-case basis. The decision should be based on the size, location, severity of the problem, and whether specialized equipment would be needed. If culvert cleaning will be addressed by a project, include the culvert locations in the plans and a cleaning special provision.
- Culvert cleaning should not normally be included in preventative maintenance projects such as pavement preservation projects.
- A list of smaller culverts (48″ and smaller), not eligible but in need of cleaning, can be sent to the appropriate MDT Maintenance Division to schedule cleaning activities.

11.2.13 Abandonment of Culverts

If the decision is made to abandon a culvert in place, rather than remove the culvert, three methods are allowed for the abandonment.

Abandon. This should be used when a culvert is either filled with silt or is shown in the as-built plans but cannot be found. It should be noted in the plans, and since it does not require any additional work, no pay item is provided.

Plug Ends and Abandon. This should be used when a culvert is being abandoned but is small enough and in deep enough fill that it does not need to be filled throughout its length. The culvert will be filled for a distance of 10 feet from each end and the culvert ends will need to be capped to prevent material from infiltrating the abandoned culvert. Crushing the ends is an acceptable means of capping culverts.

Use the Plug Ends and Abandon treatment when <u>both</u> of the following criteria exist:

- The culvert diameter is 36” or less, and
- The culvert has at least 15 feet of cover.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be plugged and abandoned.

Fill and Abandon. Culverts must be filled and abandoned when they do not meet the criteria for Plug Ends and Abandon. As a general practice, fill and abandon all storm drains that are not removed.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be filled and abandoned.

11.3 SPECIAL-PURPOSE LARGE CULVERTS

Coordinate with the Right-of-Way Bureau for stockpass and vehicular underpass requirements.

Large culverts frequently may be used for purposes other than to accommodate drainage. They may serve as stockpasses, wildlife underpasses, vehicular underpasses with surfacing, or pedestrian/bicycle underpasses. The following criteria present guidance for special-purpose large culverts.

11.3.1 Stockpasses

Record stockpass culverts in a separate summary frame. Include associated paving in the additional surfacing frame.

A standard metal pipe may be designed to serve as a stockpass by using the treatment shown in the *MDT Detailed Drawings*. It should be specified only when justified by right-of-way negotiations. The primary purpose of this structure is to serve as a stockpass. However, stockpasses may also act as cross drains. Where possible, stockpasses should be separated from drainages and the stockpass invert elevation should be set to avoid water flow. Adjacent, lower-elevation culverts may also be provided for drainage when necessary. The design team should attempt to minimize the stockpass length whenever practical. A perpendicular crossing is preferred; however, if a skew is necessary, it should not exceed 15°.

The same bedding and fill height requirements for drainage culverts also apply to stockpasses. The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.2 Wildlife Underpasses

The location and size of the culvert should be coordinated with the Environmental Resources Section.

Wildlife underpasses are intended to provide connectivity across highways while reducing collisions between vehicles and animals. The size and structure type will vary in accordance with the size and type of animal species to be accommodated and potentially by the crossing length. When a culvert is used, it is typically sunk and backfilled with natural soil and used in conjunction with wildlife exclusionary fencing. The design team should coordinate with the hydraulics designer as the culvert will often function as both a wildlife crossing and a drainage culvert.

11.3.3 Vehicular Underpasses

Specify a circular structural steel plate pipe vehicular underpass unless directed otherwise by the Hydraulics or Geotechnical Sections. Construction personnel and the design team should review the installation for special construction requirements when staged construction is specified. Granular bedding material should be specified for all large culverts.

The *MDT Detailed Drawings* show the backfill retainer and cutoff wall requirements as well as the floor surfacing criteria for the underpass. The concrete collar shown in the *MDT Detailed Drawings* will be provided for vehicular underpasses.

The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.4 Pedestrian/Bicycle Underpasses

Pedestrian and bicycle underpasses are typically designed using a 10′ x 10′ equivalent opening. These structures may include lighting, special grouting, or paving to meet ADA guidelines. All pedestrian and bicycle underpasses should be ADA-compliant up to and through the underpass from both directions. A curb to direct drainage/snowmelt around the top of the pipe should be considered.

11.4 STORM DRAINS

The detailed design of storm drains will be prepared by the hydraulics designer. The design will include the size, type, and location of the trunk line, manholes, lateral lines, and drop inlets. Refer to the *MDT Detailed Drawings* for storm drain trench and bedding details.

MDT Hydraulics Manual Chapter 14 Storm Drain Systems has additional information on storm drain design.

The design team will coordinate with the hydraulics designer to establish the locations and finished grade elevations at manholes and drop inlets, ensure that the trunk line and laterals have adequate cover, and identify conflicts with in-place utilities. The hydraulics designer will coordinate with the Utilities Section regarding utilities crossing the proposed storm drain. A SUE Phase II survey may be required to identify and avoid utility conflicts.

11.4.1 Storm Drain Inlets

The hydraulics designer will recommend the types and locations of storm drain inlets. Details for storm drain inlets are provided in the *MDT Detailed Drawings*. The roadway designer will verify the inlet locations are located at low points of sag curves and will also check the inlet locations for conflicts with curb ramps, in-place utilities, approaches, or other features. This is an iterative process and will require coordination with the Hydraulics and Utilities Sections.

A SUE Phase II survey involves identifying and locating underground utilities via evacuation of material to determine and record the utility depths and invert elevations.

11.4.2 Manholes

The size and location of manholes will be specified by the hydraulics designer. The roadway designer will check the locations for conflicts with in-place utilities. Existing manholes can be adjusted up to a maximum of one foot through the use of adjusting rings to match new grades. All manholes requiring adjustment should be identified on the plans with notes added identifying specific items required by owners (e.g., concrete collars). Manholes that have been previously adjusted, need to be lowered, or requiring adjustments greater than one foot will require additional investigation and may result in substantial modification or replacement.

11.4.3 Curb Bulb-Outs

Where curb bulb-outs are used on urban routes with curb and gutter sections, the design team should check bulb-out locations and gutter grades to determine if the bulb-outs will block the gutter flow or interfere with storm drain inlets. The hydraulics designer will determine if existing storm drain inlets should be relocated or if new inlets or other drainage features are required to maintain roadway drainage.

11.5 ROADSIDE DRAINAGE

Effective roadside drainage is one of the most critical elements in the design of a roadway. Drainage features should be designed and constructed considering the potential consequences of run-off-the-road vehicles. See Chapter 9, Section 9.3.5 for additional safety considerations and information on roadside drainage features.

Additional information on maintenance of Existing Drainage Features can be found in the *MDT PESC Design Guidelines*.

The design team should also strive to minimize interference with existing roadside drainage patterns to the extent possible. Care should be taken to maintain existing drainage patterns throughout the project and to tie into existing ditches at the project ends. If the redirection of existing flows is unavoidable, this should be discussed with the hydraulics designer, and careful attention and consideration should be given to the impacts the redirection may have on adjacent properties, flooding, and erosion.

In some cases, the existing condition intermixes roadside drainage and irrigation water and, on occasion, both may utilize the same pipes and ditches. Where practical, MDT prefers to separate the drainage and irrigation water and to move irrigation ditches and structures to outside of the right-of-way.

Under some circumstances, it is difficult or infeasible to separate the irrigation and drainage. Separating roadside drainage and irrigation may not be feasible after years of current operational patterns, and/or the additional right-of-way requirements necessary for separation may be prohibitive. If unable to separate the irrigation and drainage, replicate the existing conditions to the extent practical. Whenever the roadside ditch is used for any irrigation purpose, the design team should coordinate with the hydraulics designer.

Hydraulically designed ditches are discussed further in MDT Hydraulics Manual Chapter 10 Channel Design.

MDT does not typically perform a hydraulic design for standard roadside ditches except for erosion protection; however, a hydraulic design should be considered for the following:

- Roadside ditches that collect significant drainage,
- Storm drain outlet channels (for riprap design and drainage),
- Relocated/realigned stream channels, and
- Lined ditches and chutes.

11.5.1 Cut Sections

Roadside ditches generally use a 10-foot, 20:1-bottom configuration, and the grade of roadside ditches typically matches the profile grade of the roadway. However, more detailed ditch design needs to be considered for the following situations:

- Ditches on sustained grades may carry relatively high volumes of runoff that can result in erosion to the ditch and the cut-to-fill transition. When sustained grades are encountered, the design team needs to consider the use of erosion control features discussed in the *MDT PESC Design Guidelines.*
- Extremely flat ditches also need additional design. Separate ditch grades need to be considered for 50 feet on each side of the crest if the grades along the curve are 0.30-percent or less. Separate ditch grades may also be necessary along a superelevated section where the profile grade is 0.5-percent or less.

11.5.2 Fill Sections

Drainage considerations in fill sections generally involve the following features:

Design teams also need to conduct on-site reviews (Alignment and Grade, Plan-In-Hand) to determine the location of minor natural drainages.

- The location of minimum size (24”) culverts is often overlooked. The design team should review as-built plans to determine the location of existing culverts. When a project involves modification to the existing vertical alignment, the design team must also review the new profile grade to ensure that cross drains are provided in low spots where water would otherwise be trapped.
- Many older sections of roadway were constructed using side borrow, which resulted in substantial roadside ditches adjacent to the roadway embankment. New, wider roadway templates often fill these ditches, leaving no clear drainage path and often pushing runoff onto adjacent landowners. The design team should review these areas to ensure drainage is conveyed at the toe of the slopes. Additional ditch grading or cross drains may alleviate the problem. Construction of a drainage ditch at the toe of fill may be needed to convey runoff to a natural drainage.

11.6 MISCELLANEOUS DRAINAGE FACILITIES

11.6.1 Embankment Protectors

Embankment protectors, as shown in the *MDT Detailed Drawings*, should be installed at the corners of bridges and on high fills to control runoff unless their elimination can be justified (e.g., corners on the high side of a superelevated cross section). When the installation of embankment protectors is impractical (e.g., an embankment protector pipe would be located where it may become plugged with sediment, debris, or ice), the use of drain chutes may be considered, however, for stability, riprap drain chute slopes must be 4:1 or flatter. Do not install embankment protectors for bridges having rail configurations without curb (e.g., T101 rail)

Where drainage flows toward the structure, place embankment protectors as near to the structure as practical. On long, continuous sections of high fill, locate embankment protectors based on spread width calculated by the hydraulics designer.

11.6.2 Drainage Chutes

The drainage chutes described in the *MDT Detailed Drawings* may be used for backslope protection where the backslope intercepts a natural drainage coulee or where embankment protectors are not practical.

11.6.3 Median Inlets

Three types of median inlets are available. Each type is shown in the *MDT Detailed Drawings.* The hydraulics designer will determine the type of inlet and spacing to be used. Specify the type clearly on the plans. Tables on the applicable *MDT Detailed Drawings* present estimated quantities of materials.

11.6.4 Underdrains

The Geotechnical Section should be consulted for all subsurface recommendations. Unusual subsurface water conditions frequently are encountered during field locations and soils surveys. Some form of underdrain will be recommended by the Geotechnical Section to alleviate such conditions.

For each underdrain, the details should clearly define the location, the type, the depth of placement, and the drain aggregate and geotextile to be installed with the pipe. Outlet designs and cleanouts should also be included. On urban projects with new or existing storm drains, it can be evaluated on a case-by-case basis whether the underdrains may outlet directly into drop inlets.

11.6.5 Sidewalk Drains

Sidewalk drains may be required to drain low areas behind the sidewalk or to perpetuate drainage across sidewalks from rain gutter down pipes. Sidewalk drains may also be used to perpetuate drainage through sidewalk bulb-outs.

11.6.6 Other Facilities

Coordination with the hydraulics designer may be required for special designs such as ditch blocks, interceptor ditches, streambank protection, and detention and retention basin design. The design team will review locations and ensure that the design details are included in the plans.

11.7 IRRIGATION FACILITIES

11.7.1 Irrigation Pipe

Irrigation facilities will require water-tight pipe. In the culvert summary and the culvert summary recap, record these pipes separately and identify them as "Irrigation" or "Siphon." The hydraulics designer will provide flowline and pipe invert elevations for all irrigation installations. These elevations are critical to effective operation of the irrigation system. Irrigation pipe material will be selected by the hydraulics designer.

11.7.2 Irrigation Siphon Pipe

Some irrigation pipes will be "siphons," where the pipes are angled down under the roadway ditches with the inlet and outlet elevations higher than the pipe under the roadway centerline. The hydraulics designer will design siphons and provide the Siphon Detail Sheet.

11.7.3 Division Boxes

The hydraulics designer will provide the design and details for concrete division boxes. Some types of division boxes are shown in the *MDT Detailed Drawings*.

11.7.4 Irrigation Ditch Relocations

The hydraulics designer will provide recommendations for ditch relocations and linings, if required. Relocate longitudinal irrigation ditches outside of the right-of-way line where feasible. To avoid irrigation ditch maintenance within the roadway right-of-way, irrigation pipes 30″ in diameter and less should be extended 24″ beyond the right-of-way line where practical. The right-of-way fence may be winged into the pipe ends for irrigation pipes larger than 30″ in diameter to minimize the cost of pipe extension.

11.7.5 Inlet and Outlet Headwalls

The hydraulics designer will provide recommendations and design details for concrete headwalls. Some headwall details are included in the *MDT Detailed Drawings*.

11.8 ENCASEMENT PIPES

The request for an encasement pipe generally comes in the form of a landowner request or possibly from a municipality for a future water or sanitary sewer line. The hydraulics designer will provide a recommendation on the encasement pipe location and material type. Section 11.4.11 of the MDT Hydraulics Manual has additional information on encasement pipes

11.9 REFERENCES

1. AASHTO. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing.* AASHTO, Washington, D.C., 2013.

Exhibit 11-14
Structural Requirements for Structural Steel Plate Pipe Arch (SSPPA)

SSPPA, 6” x 2” Corrugations *31” Corner Radius*					
Pipe Dimensions① Span x Rise (in)	**Minimum Fill Height* (in)**	**Maximum Fill Height* (ft)② Minimum Metal Thickness (in)**			
		0.109	**0.138**	**0.168**	**0.188**
13'-6" x 9'-6"	30	12			
14'-2" x 9'-10"	30	12			
15'-7" x 10'-6"	30	11			
15'-10" x 10'-8"	30		10		
17'-2" x 11'-4"	30		10		
17'-11" x 11'-8"	30			9	
18'-1" x 11'-10"	30			9	
18'-9" x 12'-2"	36			9	
19'-11" x 12'-10"	36				7
20'-7" x 13'-2"	36				7

* Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.

For all SSPPA pipes, the top of the pipe should be located a minimum of 1.0 foot below the surfacing subgrade.

Notes:

① Intermediate sizes not listed have the same maximum and minimum fill heights and metal thicknesses as the next larger size listed in this table.

② Based upon a 2-ton corner bearing pressure. Special foundation investigation required when higher corner bearing pressures need to be developed.

11.2.5.4 Corrugated Aluminum Pipe (CAP)

When Corrugated Aluminum Pipe (CAP) is specified or permitted as an option, determine the metal thickness requirements from Exhibits 11-15 or 11-16 for the particular conditions of pipe shape and height of fill.

Exhibit 11-15 Structural Requirements for Corrugated Aluminum Pipe (CAP) (Lock Seam Aluminum)

2 ⅔" x ½" *Corrugations* ①, ②, ③
Lock-Seam Aluminum Pipe

Pipe Diameter (in)	Minimum Fill Height* (in)	Maximum Fill Height* (ft) Metal Thickness (in)				
		0.060	0.075	0.105	0.135	0.164
12	18	113	142			
18	18	75	94			
24	18	56	71	99		
30	18		56	79		
36	18		47	66	85	
42	18			56	73	
48	18			49	63	78
54	18			43	56	69
60	18				50	62
66	18					56
72	18					45

* Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.

For all aluminum pipes, the top of the pipe should be located a minimum of 0.3 feet below the surfacing subgrade.

Notes:

① Fill heights based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.

② For a given fill height, the wall thicknesses for both the 2 ⅔" x ½" and 3" x 1" corrugations should be compared, and the corrugations that allow the use of the thinner wall should be used.

③ Fill heights taken from manufacturers'/suppliers' product information.

Exhibit 11-16
Structural Requirements for Corrugated Aluminum Pipe (CAP) (Lock Seam Aluminum)

3” x 1” *Corrugations* ①, ②, ③ *Lock-Seam Aluminum Pipe*						
Pipe Diameter (in)	**Minimum Fill Height* (in)**	**Maximum Fill Height* (ft) Metal Thickness (in)**				
		0.060	**0.075**	**0.105**	**0.135**	**0.164**
30	18	52	65	91		
36	18	43	54	76	98	
42	18	36	46	65	84	
48	18	32	40	57	73	90
54	18	28	35	50	65	80
60	18		32	45	58	72
66	18		28	41	53	65
72	18		26	37	48	59

* Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.

For all aluminum pipes, the top of the pipe should be located a minimum of 0.3 feet below the surfacing subgrade.

Notes:

① Fill heights based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.

② For a given fill height, the wall thicknesses for both the 2⅔” x ½” and 3” x 1” corrugations should be compared, and the corrugations that allow the use of the thinner wall should be used.

③ Fill heights taken from manufacturers'/suppliers' product information.

11.2.5.5 Steel Casing Pipe (SCP)

Steel casing pipe (SCP) is typically installed by jacking and boring methods. To accommodate jacking pressures and fill heights, thicker pipe walls will be necessary as the pipe diameter increases. Jack-and-bore installations are most commonly used on projects with high fills and/or to avoid impacting the roadway cross section. Exhibit 11-17 provides minimum pipe thicknesses for SCP based upon the pipe diameter. The Contractor will need to determine if this minimum thickness is structurally sufficient for the proposed jacking and/or boring loads, and increase pipe thickness if necessary.

**Exhibit 11-17
Minimum Thicknesses
for Steel Casing Pipes
(SCP)**

Steel Casing Pipes (SCP)	
Pipe Diameter (in)	**Minimum Pipe Thickness (in)**
18	0.250
24	0.312
30	0.375
36	0.500
42	0.500
48	0.625
54	0.625
60	0.625
66	0.625
72	0.750

Table is from the following document: DEPARTMENT OF THE ARMY EM 1110-2-2902 U.S. Army Corps of Engineers Change 1 CECW-ED Washington, DC 20314-1000 Manual No. 1110-2-2902 31 March 1998 Engineering and Design CONDUITS, CULVERTS, AND PIPES Table 8-1

11.2.5.6 Plastic Pipes

High-density polyethylene (HDPE) pipe is limited for use underneath private approaches and under mainline roadways on a case-by-case basis. Solid-wall or profile-wall polyvinyl chloride (PVC) pipe may be specified for irrigation and storm drain applications on a case-by-case basis. Exhibit 11-18 presents structural requirements for plastic pipes.

Exhibit 11-18 Structural Requirements for Plastic Pipes

PLASTIC PIPES					
PIPE DIAMETER (in)	MINIMUM FILL HEIGHT* (in)	MAXIMUM FILL HEIGHT* (ft)			
		HDPE①	Profile Wall PVC ②	Solid Wall PVC ③ Pipe Stiffness (psi)	
				46	115
12	24	18	24	*24④*	*30④*
18	24	17	24	24	30
24	24	15	24	24	30
30	24	14	23	24	30
36	24	12	22	24	30
42	24	12	-	24	30
48	24	11	-	24	30

* Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.

For all plastic pipes, the top of the pipe should be located a minimum of 0.3 feet below the surfacing subgrade.

Notes:

① HDPE smooth lined or corrugated, Corrugated Polyethylene Drainage Pipe Standard Specification 708.07

② Profile Wall PVC, Standard Specification 708.05.4

③ Large Diameter Solid Wall PVC Gravity Pipe, Standard Specification 708.05.3

④ PSM PVC Solid Wall Gravity Pipe, Standard Specification 708.05.2

(AASHTO M294) *(2)*.

11.2.5.7 Road Approach Pipes

Pipes located underneath public road approaches must be at least 24” in diameter, while pipes located underneath private approaches and farm field approaches must be at least 18” in diameter. See Exhibit 11-19 for acceptable pipe cover ranges for different pipe types underneath private approaches.

Locate the entire road approach pipe, including the end treatments, outside the clear zone where practical. Flared End Treatment Sections (FETS) will be provided for all approach culverts located outside the clear zone. Where it is not practical to place approach culverts outside the clear zone, specify the 6:1 Road Approach Culvert End Treatment Section (RACETS).

Exhibit 11-19 Structural Requirements for Private Approach Pipes

Private Approach Pipes			
Pipe Size & Type	**Class of Pipe**	**Minimum Fill Height* (ft)**	**Maximum Fill Height* (ft)**
18" RCP	2	①	①
	3	1.5	15
	4	0.5	22
	5	0.5	33
18" CSP	--	1	142
18" CAP	--	1.5	75
18" HDPE	--	2	17

* Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.

Notes:

① Class 2 reinforced concrete pipe does not exist for 18" diameter pipe.

11.2.6 Multiple Pipe Installations

It may be necessary to install two or more adjacent culverts at one location to provide adequate conveyance. Multiple pipe installations are identified as a "double" or a "triple" installation at the station representing the center of the installation.

The spacing between outside faces of adjacent pipes normally will be a minimum of 4 feet, but may be increased to a maximum of 8 feet to aid in installation and backfill. If FETS are used, specify at least 2 feet between the outside ends of adjacent terminal sections.

11.2.7 Special Culvert Installations

The potential for settlement at or near larger culverts should be evaluated and addressed during the preconstruction phases. Settlement issues at or near a large culvert could be due to either settlement of the foundation soil below the culvert or where achieving adequate compaction of backfill around the culvert may be problematic (ultimately leading to differential settlement).

If none of these seven conditions/parameters is present, then standard culvert design practices and procedures should be followed.

A special culvert installation is needed if one or more of the following conditions/parameters are present:

1. Large culverts: 10-foot diameter (or equivalent arch pipe) or greater (difficult to obtain compaction below pipe haunches);
2. Low fill heights/cover above the culvert (5 feet or less) measured from top of culvert to top of pavement section;

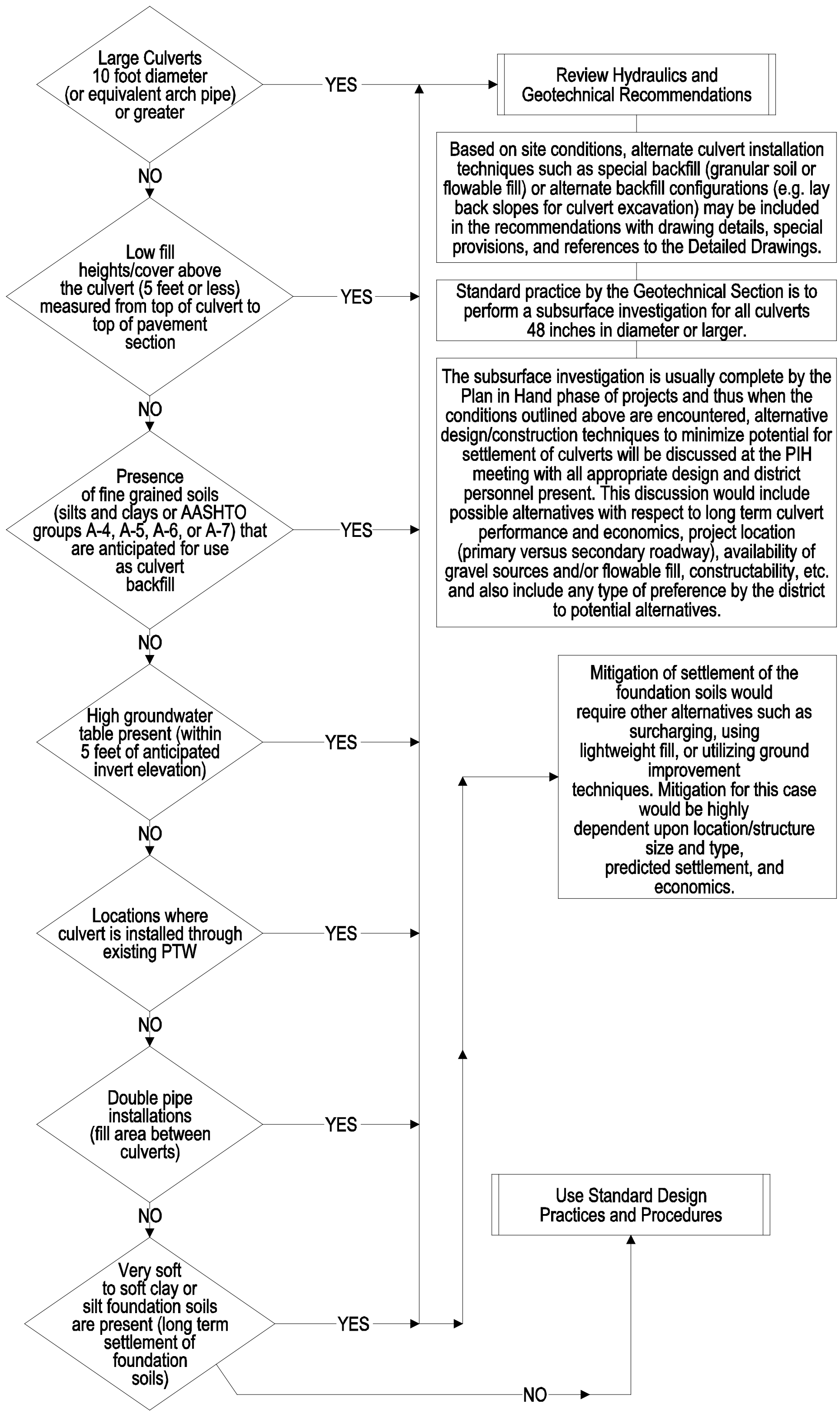
3. Presence of fine-grained soils (silts and clays or AASHTO groups A-4, A-5, A-6, or A-7) that are anticipated for use as culvert backfill;
4. High groundwater table present (within 5 feet of anticipated invert elevation);
5. Locations where culvert is installed through the existing present travel way (PTW). A widened PTW can lead to differential settlement and/or areas where a vertical trench excavation might be used to install culverts;
6. Multiple pipe installations (fill area between culverts); or
7. Very soft to soft clay or silt foundation soils are present (long-term settlement of foundation soils).

If a special culvert installation is needed, then evaluate alternate culvert installation and backfill techniques as follows:

- Review the hydraulics designer's and Geotechnical Section Recommendations.
- Based on site conditions, alternate culvert installation techniques such as special backfill (granular soil or flowable fill) or alternate backfill configurations (e.g., lay backslopes for culvert excavation) may be included in the recommendations along with drawing details, special provisions, and references to the *MDT Detailed Drawings*.
- When No. 7 above is encountered, mitigation of settlement of the foundation soils would require other alternatives such as surcharging, using lightweight fill, or utilizing ground improvement techniques. Mitigation for this case would be highly dependent upon location/structure size and type, predicted settlement, and economics.
- Standard practice by the Geotechnical Section is to perform a subsurface investigation for all culverts 48" in diameter or larger. As part of the subsurface investigation, items No. 3, 4, and 7 should be identified by the Geotechnical Section. The remaining items will be readily known from the proposed project Scope of Work, hydraulic design reports, and plans/cross sections.
- The subsurface investigation is usually complete by the Plan-In-Hand (PIH) phase of projects and thus when the conditions outlined above are encountered, alternative design/construction techniques to minimize potential for settlement of culverts will be discussed at the PIH meeting with all appropriate design and District personnel present. This discussion would include possible alternatives with respect to long term culvert performance and economics, project location (primary versus secondary roadway), availability of gravel sources and/or flowable fill, constructability, etc., and also include any type of preference by the District to potential alternatives.

If none of the above seven conditions/parameters is present, then standard culvert design practices and procedures should be followed. Exhibit 11-20 presents the guidelines described above for determining the need for special culvert installation and presents the coordination items the design team should complete to perform the design of a special culvert installation.

Exhibit 11-20
Special Culvert
Installation Guidelines



11.2.8 Culvert End Treatments

Special treatments are typically required for the ends of culvert installations. Exhibit 11-21 provides criteria for determining the proper end treatments for cross drain structures based upon pipe type and size. These end treatment criteria apply to both single- and multiple-pipe installations. Refer to Chapter 9 for detailed information on the proper use and installation of culvert end treatments in relation to roadside safety best practices.

See the *MDT Detailed Drawings* for the standard culvert end treatments.

Exhibit 11-21
Culvert End Treatment Determination

Pipe Type and Size	End Treatment	Cutoff Walls	Inlet/Outlet Concrete Edge Protection
RCP ≤ 48"	FETS	No	No
RCP ≥ 54”	FETS	Yes	No
RCPA ≥ 65" x 40"	FETS	Yes	No
CMP ≤ 48”	FETS	No	No
CMP ≥ 54"	Step Bevel①	Yes	Yes
CSPA or SSPPA ≥ 54"	Bevel①	Yes	Yes
SCP ≤ 48”	FETS	No	No
SCP ≥ 54"	Square	Yes	Yes

CMP = Corrugated Metal Pipe (CSP or CAP)

FETS = Flared End Terminal Section

Notes:

① Type of bevel will be identified on the plans and culvert summary frame (e.g., 2:1 step bevel, 2:1 bevel).

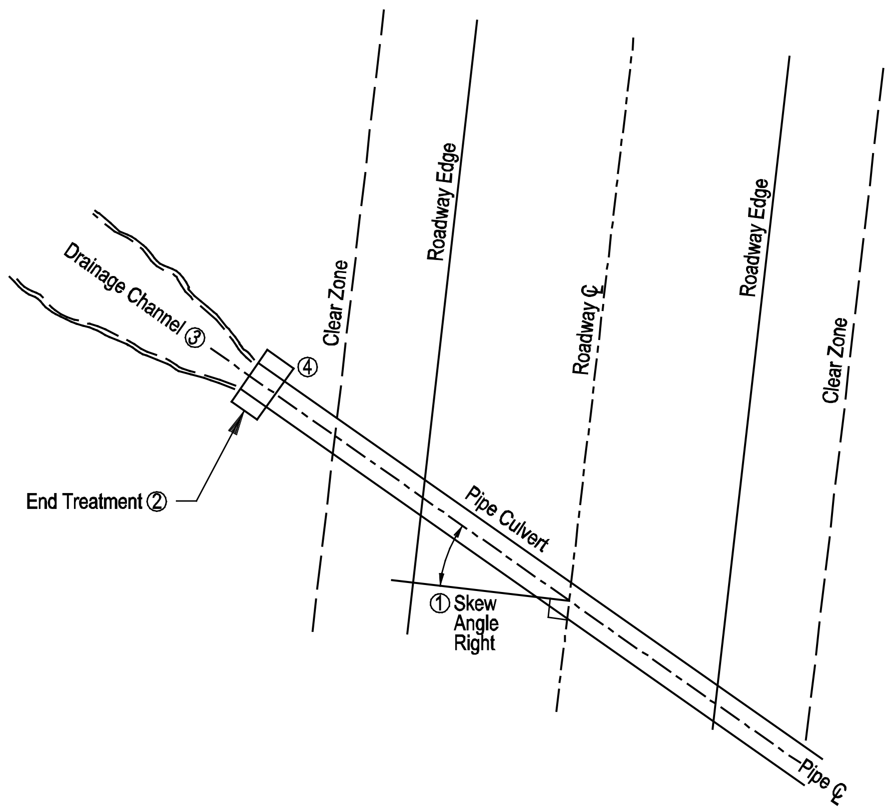
② In special situations, square ends may be specified by the hydraulics designer. For square ends on culverts ≤ 48” or equivalent, the culvert length should be extended 2 feet beyond the toe of the fill slope. For square ends on culverts ≥ 54” or equivalent, add cutoff walls and concrete edge protection to the inlet and outlet.

11.2.8.1 Skewed Pipe Installations

The skew is defined as the angle measured left or right from a line which is perpendicular to the roadway centerline. See Exhibit 11-22 for a general illustration of pipe skew in relation to the roadway orientation.

Concrete pipes shall not be beveled or skew-beveled.

Exhibit 11-22
Pipe Skew



① Pipe skews will typically not exceed 35 degrees. A skew angle right is one where the pipe centerline is to the right of a line extended perpendicular from the roadway centerline. A skew angle left is one where the pipe centerline is to the left of a line extended perpendicular from the roadway centerline.

② The end treatments for all single concrete pipe and corrugated steel pipe installations with diameters 48” or less will be installed perpendicular to the centerline of the pipe regardless of pipe skew, unless specified otherwise by the hydraulics designer.

The following will apply to installations of corrugated steel and structural steel plate pipe diameters 54” or greater:

For skew angles 0° to 15°, the end treatment should be perpendicular to the centerline of the pipe.

For skew angles 16° to 35° and fill height 10 feet or less, the end treatment should generally be skew-beveled. The design team should verify this with the hydraulics designer.

For skew angles 16° to 35° and fill height greater than 10 feet, the end treatment should generally be perpendicular to the centerline of the pipe and the fill warped to the pipe ends. The design team should verify this with the hydraulics designer.

③ Consider channel realignment changes where appropriate, with consideration of potential environmental impacts, to limit pipe skew.

④ The pipe should be extended so that the near corner of the edge protection catches the fill slope beyond the clear zone.

Skewed Installations. Concrete pipes cannot be beveled or skew beveled. The design team should note the following considerations for metal pipe end treatments with skewed installations for pipe diameters of 54″ or greater:

- Multiple-pipe installations will use the same end treatment as single-pipe installations except that, for skews from 16° to 35°, the end treatment will be skew-beveled regardless of fill height.
- Skew-bevel or skew step-bevel end sections are cut parallel to the centerline of the roadway.
- If it is determined necessary to skew-bevel a pipe end, provide concrete edge protection and cutoff walls on both ends.
- The type of bevel and the amount of skew are to be identified in the culvert summary.
- If temporary bracing of skew-beveled pipe ends is required, it must be addressed by special provision.

11.2.8.2 Inlet and Outlet Edge Protection

The hydraulic characteristics of some drainage channels may require special protection for the roadway embankment at the inlets and outlets of pipe installations. The hydraulics designer will provide design information for special features.

If skew-bevels are used, concrete edge protection is required to strengthen the top arch on the pipe inlet and outlet. Bolting should follow the *MDT Detailed Drawings*.

If a culvert requiring edge protection is skewed, the design team should design the edge protection to match the roadway inslope and extend the culvert sufficiently to be adequately protected by the edge treatment.

For metal pipes 48″ or less in diameter, it is not necessary to provide for special protection unless the hydraulics designer provides specific recommendations to do so. For metal pipes 54″ or larger in diameter, provide the protective measures described in the *MDT Detailed Drawings*, as applicable:

- Cutoff walls at both ends, and
- Concrete edge protection at inlet and outlet.

See the *MDT Detailed Drawings* and *MDT Hydraulics Standard Drawings* for estimated quantities for cutoff walls and inlet and outlet edge protection.

Concrete pipes 54″ or larger in diameter with FETS require cutoff walls at both ends. Concrete edge protection should not be used unless specified by the hydraulics designer. Riprap edge protection should not be used in conjunction with the standard end treatment for concrete pipe unless specified by the hydraulics designer.

11.2.9 Pipe Bedding/Foundation

Bedding is required for all pipe installations per the *MDT Detailed Drawings*. For pipes 48″ in diameter or less, bedding is paid for within the cost of the pipe and does not need to be shown in the culvert summary. For pipes 54″ or larger in diameter, granular bedding must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

When foundation material is specified, it will be placed below the granular bedding or bedding material. Foundation material must be quantified and paid for separately and specified in the culvert summary in accordance with the *MDT Detailed Drawings*.

11.2.10 Riprap

The hydraulics designer will typically design embankment protection, outlet aprons, and other features requiring riprap. The hydraulics designer will work with the design team to calculate quantities and provide the necessary details. Show the riprap on the plans and cross sections and include the quantities in the appropriate summary.

The layout and quantities of riprap at bridge ends will be coordinated between the design team, the hydraulics designer, and the Bridge Bureau. Riprap will be shown on both the plan and profile, and the quantities will be included in the appropriate summary. Riprap details may need to be included in the plan set. Geotextile will be provided with all riprap installations unless otherwise specified.

11.2.11 Metal Culvert Extensions

The following will apply for metal culvert extensions:

- The hydraulics designer will evaluate the remaining service life of the pipe to determine if it should be extended or replaced. This determination is generally based on the condition of the in-place pipes.
- The length of extension includes the new end treatment section, unless the existing section will be removed and re-laid. Note this in the culvert summary.

Re-lay means to reinstall the existing culvert end treatment rather than installing a new end treatment.

- The design team is responsible for determining the length of pipe extensions. The hydraulics designer may recommend new end treatments on a case-by-case basis.
- If the existing pipe is a metric size, the diameter will be converted to US Customary units and rounded to the nearest inch (e.g., 600mm = 24 inches). The pipe extensions will be called out using the available US Customary size for the pipe.
- The thickness of the extension pipe should match the existing pipe thickness (e.g., a 0.064″ thick pipe extension should not be connected to an existing pipe that is 0.079″ thick).
- When the material or configuration of the existing pipe cannot be matched, a concrete collar will be needed to connect the extension to the existing pipe. Metal bands can be used to connect CSP to SSPP where the connection is beyond the edge of the surfacing section. This connection will require a special detail, and a CSP Verification special

provision will typically be included, requiring the contractor to verify the existing CSP pipe dimensions prior to lengthening.
- Fill height for pipe extensions will be measured at the point of connection to the existing pipe unless otherwise specified.

11.2.12 Reinforced Concrete Pipe Extensions

The required minimum length of extension for reinforced concrete pipe is as follows (length is measured from the end of the existing pipe barrel minus the existing end treatment or any damaged pipe sections.):

- Diameter ≤ 30″: 10 feet, including 4 feet of new pipe and a 6-foot standard terminal section.
- 30″ < Diameter ≤ 72″: 12 feet, including 4 feet of new pipe and an 8-foot standard terminal section.
- Diameter > 72″: Contact the hydraulics designer.
- If extension of the barrel is not required, a FETS can be added without any additional length of pipe.
- Fill height for pipe extensions should be measured at the point of connection to the existing pipe.
- Connection to the existing RCP pipe can be made by matching the existing RCP joint, utilizing an RCP Adapter Ring in accordance with the *MDT Detailed Drawings*, or a Field Cast Concrete Connection in accordance with the *MDT Detailed Drawings*.

11.2.13 Culvert Cleaning

It may be desirable to include cleaning of existing culverts with design projects. The following guidelines should be followed to determine and document whether a culvert is eligible for cleaning on projects involving Federal-aid funds:

These guidelines on culvert cleaning apply only to projects involving Federal-aid funds.

- Only culverts larger than 48″ are eligible to be cleaned with Federal-aid funds. All culverts larger than 48″ will be evaluated for cleaning on a case-by-case basis. The decision should be based on the size, location, severity of the problem, and whether specialized equipment would be needed.
- Culvert cleaning should not normally be included in preventative maintenance projects.
- A list of smaller culverts (48″ and smaller), not eligible but in need of cleaning, can be sent to the appropriate MDT Maintenance Division to schedule cleaning activities.

11.2.14 Abandonment of Culverts

If the decision is made to abandon a culvert in place, rather than remove the culvert, three methods are allowed for the abandonment.

Abandon. This should be used when a culvert is either filled with silt or is shown in the as-built plans but cannot be found. It should be noted in the plans, and since it does not require any additional work, no pay item is provided.

Plug Ends and Abandon. This should be used when a culvert is being abandoned but is small enough and in deep enough fill that it does not need to be filled throughout its length. The culvert will be filled for a distance of 10 feet from each end and the culvert ends will need to be capped to prevent material from infiltrating the abandoned culvert. Crushing the ends is an acceptable means of capping culverts.

Use the Plug Ends and Abandon treatment when both of the following criteria exist:

- The culvert diameter is 36" or less, and
- The culvert has at least 15 feet of cover.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be plugged and abandoned and include a special provision in the plans.

Fill and Abandon. Culverts must be filled and abandoned when they do not meet the criteria for Plug Ends and Abandon. As a general practice, fill and abandon all storm drains that are not removed.

Refer to Chapter 13 for information on calculating the quantity of culverts that are to be filled and abandoned and include a special provision in the plans.

11.3 SPECIAL-PURPOSE LARGE CULVERTS

Coordinate with the Right-of-Way Bureau for stockpass and vehicular underpass requirements.

Large culverts frequently may be used for purposes other than to accommodate drainage. They may serve as stockpasses, wildlife underpasses, vehicular underpasses with surfacing, or pedestrian/bicycle underpasses. The following criteria present guidance for special-purpose large culverts.

11.3.1 Stockpasses

Record stockpass culverts in a separate summary frame. Include associated paving in the additional surfacing frame.

A standard metal pipe may be designed to serve as a stockpass by using the treatment shown in the *MDT Detailed Drawings*. It should be specified only when justified by right-of-way negotiations. The primary purpose of this structure is to serve as a stockpass. However, stockpasses may also act as cross drains. Where possible, stockpasses should be separated from drainages and the stockpass invert elevation should be set to avoid water flow. Adjacent, lower-elevation culverts may also be provided for drainage when necessary. The design team should attempt to minimize the stockpass length whenever practical. A perpendicular crossing is preferred; however, if a skew is necessary, it should not exceed 15°.

The same bedding and fill height requirements for drainage culverts also apply to stockpasses. The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.2 Wildlife Underpasses

Wildlife underpasses are intended to provide connectivity across highways while reducing collisions between vehicles and animals. The size and structure type will vary in accordance with the size and type of animal species to be accommodated and potentially by the crossing length. When a culvert is used, it is typically sunk and backfilled with natural soil and used in conjunction with wildlife exclusionary fencing. The design team should coordinate with the hydraulics designer as the culvert will often function as both a wildlife crossing and a drainage culvert.

The location and size of the culvert should be coordinated with the Environmental Resources Section.

11.3.3 Vehicular Underpasses

Specify a circular structural steel plate pipe vehicular underpass unless directed otherwise by the Hydraulics or Geotechnical Sections. Construction personnel and the design team should review the installation for special construction requirements when staged construction is specified. Granular bedding material should be specified for all large culverts.

The *MDT Detailed Drawings* show the backfill retainer and cutoff wall requirements as well as the floor surfacing criteria for the underpass. The concrete collar shown in the *MDT Detailed Drawings* will be provided for vehicular underpasses.

The design team should adhere to the maximum and minimum fill height requirements in the fill height exhibits.

11.3.4 Pedestrian/Bicycle Underpasses

Pedestrian and bicycle underpasses are typically designed using a 10′ x 10′ equivalent opening. These structures may include lighting, special grouting, or paving to meet ADA guidelines. All pedestrian and bicycle underpasses should be ADA-compliant up to and through the underpass from both directions. A curb to direct drainage/snowmelt around the top of the pipe should be considered.

11.4 STORM DRAINS

The detailed design of storm drains will be prepared by the hydraulics designer. The design will include the size, type, and location of the trunk line, manholes, lateral lines, and drop inlets. Refer to the *MDT Detailed Drawings* for storm drain trench and bedding details.

The design team will coordinate with the hydraulics designer to establish the locations and finished grade elevations at manholes and drop inlets, ensure that the trunk line and laterals have adequate cover, and identify conflicts with in-place utilities. The hydraulics designer will coordinate with the Utilities Section regarding utilities crossing the proposed storm drain. A SUE2 survey may be required to identify and avoid utility conflicts.

A SUE2 survey involves identifying and locating underground utilities via evacuation of material to determine and record the utility depths and invert elevations.

11.4.1 Storm Drain Inlets

The hydraulics designer will recommend the types and locations of storm drain inlets. Details for storm drain inlets are provided in the *MDT Detailed Drawings*. The roadway designer will verify the inlet locations are located at low points of sag curves and will also check the inlet locations for conflicts with curb ramps, in-place utilities, approaches, or other features. This is an iterative process and will require coordination with the Hydraulics and Utilities Sections.

11.4.2 Manholes

The size and location of manholes will be specified by the hydraulics designer. The roadway designer will check the locations for conflicts with in-place utilities. Existing manholes can be adjusted up to a maximum of one foot through the use of adjusting rings to match new grades. All manholes requiring adjustment should be identified on the plans with notes added identifying specific items required by owners (e.g., concrete collars). Manholes that have been previously adjusted, need to be lowered, or requiring adjustments greater than one foot will require additional investigation and may result in substantial modification or replacement.

11.4.3 Curb Bulb-Outs

Where curb bulb-outs are used on urban routes with curb and gutter sections, the design team should check bulb-out locations and gutter grades to determine if the bulb-outs will block the gutter flow or interfere with storm drain inlets. The hydraulics designer will determine if existing storm drain inlets should be relocated or if new inlets or other drainage features are required to maintain roadway drainage.

11.5 ROADSIDE DRAINAGE

Effective roadside drainage is one of the most critical elements in the design of a roadway. Drainage features should be designed and constructed considering the potential consequences of run-off-the-road vehicles. See Chapter 9, Section 9.3.5 for additional safety considerations and information on roadside drainage features.

Additional information on maintenance of Existing Drainage Features can be found in the *MDT PESC Design Guidelines*.

The design team should also strive to minimize interference with existing roadside drainage patterns to the extent possible. Care should be taken to maintain existing drainage patterns throughout the project and to tie into existing ditches at the project ends. If the redirection of existing flows is unavoidable, this should be discussed with the hydraulics designer, and careful attention and consideration should be given to the impacts the redirection may have on adjacent properties, flooding, and erosion.

Drainage in the roadside ditch sometimes is made complicated by landowners who use the roadside ditch to carry irrigation wastewater. Although MDT prefers to have separate irrigation wastewater ditches constructed outside of the roadway right-of-way, perpetuation of irrigation wastewater in the roadside ditch should be evaluated on a case-by-case basis. Whenever the roadside ditch is used for any irrigation purpose, the design team should coordinate with the hydraulics designer.

11.5.1 Cut Sections

Roadside ditches generally use a 10-foot, 20:1-bottom configuration, and the grade of roadside ditches typically matches the profile grade of the roadway. However, more detailed ditch design needs to be considered for the following situations:

- Ditches on sustained grades may carry relatively high volumes of runoff that can result in erosion to the ditch and the cut-to-fill transition. When sustained grades are encountered, the design team needs to consider the use of erosion control features discussed in the *MDT PESC Design Guidelines.*
- Extremely flat ditches also need additional design. Separate ditch grades need to be considered for 50 feet on each side of the crest if the grades along the curve are 0.30-percent or less. Separate ditch grades may also be necessary along a superelevated section where the profile grade is 0.5-percent or less.

11.5.2 Fill Sections

Drainage considerations in fill sections generally involve the following features:

Design teams also need to conduct on-site reviews (Alignment and Grade, Plan-In-Hand) to determine the location of minor natural drainages.

- The location of minimum size (24") culverts is often overlooked. The design team should review as-built plans to determine the location of existing culverts. When a project involves modification to the existing vertical alignment, the design team must also review the new profile grade to ensure that cross drains are provided in low spots where water would otherwise be trapped.
- Many older sections of roadway were constructed using side borrow, which resulted in substantial roadside ditches adjacent to the roadway embankment. New, wider roadway templates often fill these ditches, leaving no clear drainage path and often pushing runoff onto adjacent landowners. The design team should review these areas to ensure drainage is conveyed at the toe of the slopes. Additional ditch grading or cross drains may alleviate the problem. Construction of a drainage ditch at the toe of fill may be needed to convey runoff to a natural drainage.

11.6 MISCELLANEOUS DRAINAGE FACILITIES

11.6.1 Embankment Protectors

Embankment protectors, as shown in the *MDT Detailed Drawings*, should be installed at the corners of bridges and on high fills to control runoff unless their elimination can be justified (e.g., corners on the high side of a superelevated cross section). When the installation of embankment protectors is impractical (e.g., an embankment protector pipe would be located where it may become plugged with sediment, debris, or ice), the use of drain chutes may be considered. Do not install embankment protectors for bridges having rail configurations without curb (e.g., T101 rail). Typical installations for bridges are described as follows:

1. Four-lane divided roadway on tangent:
    a. Embankment protectors at the four outside corners.
    b. Concrete curb at the four inside (median side) corners.
    c. Median drains with median inlet and cross drain, or an outlet between structures with embankment protection. Ditch blocks should be installed at the median inlet, and concrete curbs should be installed from the bridge ends to intercept drainage and prevent it from eroding the material at the ends of the structure wingwalls.
2. Four-lane divided roadway on curve:
    a. Embankment protectors on the two outside corners on the low side of the curve.
    b. Concrete curb at the two inside (median side) corners on the low side of the curve.
    c. Median inlets same as on tangent section.
3. Two-lane or four-lane with narrow median:
    a. On tangent: embankment protectors at the four corners.
    b. On curve: embankment protectors at the two corners on the low side of the curve.

Where drainage flows toward the structure, place embankment protectors as near to the structure as practical. On long, continuous sections of high fill, locate embankment protectors based on spread width calculated by the hydraulics designer.

11.6.2 Drainage Chutes

The drainage chutes described in the *MDT Detailed Drawings* may be used for backslope protection where the backslope intercepts a natural drainage coulee or where embankment protectors are not practical.

11.6.3 Median Inlets

Three types of median inlets are available. Each type is shown in the *MDT Detailed Drawings.* The hydraulics designer will determine the type of inlet and spacing to be used. Specify the type clearly on the plans. Tables on the applicable *MDT Detailed Drawings* present estimated quantities of materials.

11.6.4 Underdrains

The Geotechnical Section should be consulted for all subsurface recommendations. Unusual subsurface water conditions frequently are encountered during field locations and soils surveys. Some form of underdrain will be recommended by the Geotechnical Section to alleviate such conditions.

For each underdrain, the details should clearly define the location, the type, the depth of placement, and the drain aggregate and geotextile to be installed with the pipe. Outlet designs and cleanouts should also be included. On urban projects with new or existing storm drains, it can be evaluated on a case-by-case basis whether the underdrains may outlet directly into drop inlets.

11.6.5 Sidewalk Drains

Sidewalk drains may be required to drain low areas behind the sidewalk or to perpetuate drainage across sidewalks from rain gutter down pipes. Sidewalk drains may also be used to perpetuate drainage through sidewalk bulb-outs.

11.6.6 Other Facilities

Coordination with the hydraulics designer may be required for special designs such as ditch blocks, interceptor ditches, streambank protection, and detention and retention basin design. The design team will review locations and ensure that the design details are included in the plans.

11.7 IRRIGATION FACILITIES

11.7.1 Irrigation Pipe

Irrigation facilities will require water-tight pipe. In the culvert summary and the culvert summary recap, record these pipes separately and identify them as "Irrigation" or "Siphon." The hydraulics designer will provide flowline and pipe invert elevations for all irrigation installations. These elevations are critical to effective operation of the irrigation system. Irrigation pipe material will be selected by the hydraulics designer.

11.7.2 Irrigation Siphon Pipe

Some irrigation pipes will be "siphons," where the pipes are angled down under the roadway ditches with the inlet and outlet elevations higher than the pipe under the roadway centerline. The hydraulics designer will design siphons and provide the Siphon Detail Sheet.

11.7.3 Division Boxes

The hydraulics designer will provide the design and details for concrete division boxes. Some types of division boxes are shown in the *MDT Detailed Drawings*.

11.7.4 Irrigation Ditch Relocations

The hydraulics designer will provide recommendations for ditch relocations and linings, if required. Relocate longitudinal irrigation ditches outside of the right-of-way line where feasible. To avoid irrigation ditch maintenance within the roadway right-of-way, irrigation pipes 30″ in diameter and less should be extended 24″ beyond the right-of-way line where practical. The right-of-way fence may be winged into the pipe ends for irrigation pipes larger than 30″ in diameter to minimize the cost of pipe extension.

11.7.5 Inlet and Outlet Headwalls

The hydraulics designer will provide recommendations and design details for concrete headwalls. Some headwall details are included in the *MDT Detailed Drawings*.

11.8 ENCASEMENT PIPES

This section is intended to provide general guidelines for material selection when specifying an encasement pipe for proposed pressure irrigation lines, sanitary sewers, and water lines. The request for an encasement pipe generally comes in the form of a landowner request or possibly from a municipality for a future water or sanitary sewer line. Encasement pipes may be required for the following reasons:

- Prevent damage to structures caused by soil erosion or settlement in case of pipe failure or leakage.
- Allows economical pipe removal and replacement in the future.
- Accommodate regulations or requirements imposed by public or private owners of property in which the pipe is installed.
- Allows boring rather than excavation where open excavation would be impossible or prohibitively expensive.

In general, MDT prefers to provide uncased pipeline crossings through the roadway. In these circumstances, the following materials can be considered for pipeline crossings:

- PVC Pressure Water Pipe
- Ductile Iron Water Pipe
- Steel Water Pipe

When installation of an encasement pipe is warranted, the following encasement pipe materials may be considered. See the *MDT Hydraulics Manual* for specific encasement pipe application guidelines for each material.

- Corrugated Steel Pipe (CSP)
- PVC Gravity Sewer and Drain Pipe (SDR 35)
- High Density Polyethylene (HDPE) - *Subject to review and approval of the hydraulics designer*
- Steel Casing Pipe (SCP)
- Reinforced Concrete Pipe (RCP)

11.9 REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO). *Model Drainage Manual.* AASHTO, Washington, D.C., 2014.
2. AASHTO. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing.* AASHTO, Washington, D.C., 2013.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 12

Plan Preparation

September 2016

Contents

Chapter 12

Plan Preparation

Chapters 1 through 11 in the *MDT Road Design Manual* provide uniform criteria and procedures for the geometric design of a highway facility. These designs must be incorporated into the contract plans so that they can be clearly understood by contractors, material suppliers, and MDT construction personnel assigned to supervise and inspect the construction of the project. For consistent interpretation of the contract plans on all projects, individual sheets should have a standard format and content, and the sequence of plan assembly should generally be the same. To provide this consistency, this chapter provides guidelines for the uniform preparation of contract plans, including recommended plan sequence, drafting guidelines, and plan sheet content. Sample plans, providing examples and clarification to the information in this chapter, are available at the following link on the MDT Website:

MDT Sample Plans

In addition to this guidance, the design team should follow MDT's Computer-Aided Design & Drafting (CADD) Standards, which can be found at the following link on the MDT Website:

MDT CADD Standards

12.1 GENERAL INFORMATION

12.1.1 Construction Plan Sheet Organization

12.1.1.1 Plan Sequence

All Plan Sheet Sizes are 11" x 17".

To provide consistency from project to project, assemble the construction plan sheets in the sequence below. Not all plans will have all the sheets, and several sheets can be combined together (e.g., Table of Contents, Notes). If several sheets are combined, the sequence below still should be followed; that is, they should be listed in order from left to right on the sheet. The recommended plan sequence is as follows:

1. Title Sheet
2. Table of Contents
3. Notes
4. Linear and Level Data
5. Control Diagram and Abstract Table
6. Typical Sections
7. Summaries
8. Hydraulic Data Summary
9. Detail Sheets:
    a. Drainage details (including storm drains);
    b. Special maintenance and protection of traffic through construction zone details (e.g., detours);
    c. Miscellaneous details (including details for major approaches, interchanges, or connections to existing pavement);
    d. Mass diagram. (not included in final construction plans)
10. Plan and Profile Sheets
11. Sanitary Sewer Plans (included in the plans if designed by a Consultant)
12. Water Plans (included in the plans if designed by a Consultant)
13. Signing Plans:
    a. Summary Signing and Delineation Quantities Sheet
    b. Sign Location and Specifications Sheets
    c. Signing Detail Sheets
    d. Plan Sheets
14. Electrical Plans:
    a. Electrical Quantity Summary Sheet
    b. Electrical Detail Sheets
    c. Plan Sheets
15. Bridge Plans:
    a. Title/Quantity Sheet
    b. General Layout of Structure Sheet
    c. Footing Plan Sheet
    d. Bent/Pier Sheet
    e. Erection Plan Sheet
    f. Beam/Girder Sheet
    g. Slab Detail Sheet
    h. Detail Sheets
    i. Standard Sheets

Items 11 through 15 are included in the standard order that they appears in the contract plans; however, guidance for their preparation is not provided in the RDM. Refer to Bridge, Traffic, or other Design Manuals, as appropriate.

16. Cross Sections:
    a. Mainline (including detours)
    b. Approach cross sections (if applicable)
    c. Miscellaneous cross section items (berms, ditches, and shared use paths that are not already shown on mainline cross sections)
    d. Skewed culverts (cross section shown along the skew of the culvert)

12.1.1.2 Sheet Numbering

The Title Sheet will be considered as sheet one, but it will not be numbered. Number all other sheets sequentially with single numbers only in the lower right-hand corner. Sheet counts (e.g., 25 of 135) are not to be included in the sheet numbering.

Use a consistent numbering system without a hyphen (e.g., S1).

Number road plans with separate, sequential whole numbers. Number cross section sheets with separate, sequential whole numbers beginning with 1. Sanitary sewer, water, signing, electrical and bridge plans will be numbered separately within each group beginning with 1 and will have the following letter prefixes:

1. Sanitary Sewer Plans — SS*
2. Water Plans — WS*
3. Signing Plans — S
4. Electrical Plans — E
5. Bridge Plans — B

   * The Sanitary Sewer and Water Plans will only be designated by the SS and WS prefixes for new installations or extensive modifications to existing systems. The details for minor modifications or additions to existing systems will typically be included in the road plans without a prefix designation. The determination to separate the sanitary sewer and water line details from the road plan details will be made at the Plan-in-Hand.

12.2 DESIGN AND DRAFTING GUIDELINES

12.2.1 General Drafting Guidelines

The following provides general guidelines for the plotting of survey data and design details on the plan sheets:

1. **Abbreviations.** The *MDT Detailed Drawings* present a listing of the common abbreviations that should be used where it is necessary to abbreviate elements within the set of plans.
2. **Stationing.** Stations of 100 feet are used by MDT. Show each station as a half tic mark, and denote every tenth station with a full tic mark.
3. **Sheet Breaks.** Each plan sheet should typically show 3,000 feet of the project location for rural projects, with no overlap between sheets. For

urban projects, the plan view may be scaled up (1”=40’) to show 600 feet of the project on a sheet.

4. **North Arrow.** The standard north arrow should be shown on the title sheet as well as on all plan and detail sheets.
5. **Project Block.** All sheets (except the title sheet) should have a standard block in the lower right-hand corner indicating the following:
    - County
    - Project Title
    - Construction (CN) Project Number
    - Combination Scale Factor (CSF)
    - Uniform Project Number (UPN)
    - Sheet Number

    Note: The Preliminary Engineering (PE) Project Number is not used in the plans. The only place the PE Project Number should be listed is on the title sheet in the Associated Project Agreement Numbers Block.

12.2.2 Plotting Survey Data

For surveys conducted by aerial survey, the Photogrammetry and Survey Section will be responsible for plotting the survey data. For data collector surveys, the surveyor will provide a three-dimensional (3D) MicroStation file with graphical triangles for the design team to create a Digital Terrain Model (DTM) and a two-dimensional (2D) MicroStation file with the topographic information to be used as a base map. For manually conducted surveys, the design team will be responsible for plotting the survey data using the MDT-approved Computer Aided Design & Drafting (CADD) system. In addition to the field notes, the design team should obtain a copy of the as-built plans (if available) for informational purposes. The as-built plans may be obtained at the MDT Central Office in Helena if not available electronically.

The *MDT Survey Manual* provides MDT's criteria for plotting the survey field notes *(1)*. In general, plot the survey 700 feet beyond the proposed project limits.

Global Positioning System (GPS) surveys are typically used for MDT projects, utilizing the North American Datum (NAD) 83 State Plane Coordinate Systems. For projects of extremely limited size and scope, local coordinates may be used with an established point assigned a set of coordinate values and the coordinates for all other points are calculated from these assumed values.

12.3 PLAN SHEET CONTENT

Prepare the construction plans as simply as practical. Avoid the use of duplicate data and unnecessary cross references. Road Design Sample Plans provide model drawings for various plan sheets. The following sections provide additional information on what should be included within each sheet.

12.3.1 Title Sheet

The Title Sheet is the front cover for a plan set. It identifies the project type, project location and other pertinent project information. Pre-drafted title sheets are available as reference files. Pre-drafted sheets provide the State map and blocks for design data, project approvals, related projects, and associated project agreement numbers. Also shown is the MDT name and fields for entering title information and project length.

The Title Sheet should contain the following information:

1. **State Map.** A state map in the upper left-hand corner of the sheet should show the general location of the project in relation to other roads within the State. An arrow labeled "THIS PROJECT" will indicate the project location.
2. **Title Information.** Show the project title information in the top center of the sheet below the MDT name in the following order:
   a. Project construction (CN) number as provided by the Fiscal Programming Section.
   b. Brief project description as provided in the Program and Project Management System (PPMS).
   c. Project name. The project name must match the name on the project's programming document.
   d. Access control note, if applicable.
   e. County name.
3. **Project Length.** Show the length of the project to the nearest tenth of a mile immediately below the title information. There are exceptions for statewide projects and multiple site projects.
4. **Surfacing Source**. To the right of the project length, indicate whether or not the surfacing source is contractor furnished for the project.
5. **Design Data.** Include project design data in a block in the upper right-hand corner. For those projects having two or more road segments with different design data, prepare separate design data blocks for each segment.
6. **Combination Scale Factor (CSF).** Show the CSF(s) for the project just below the design data.
7. **Layout Map.** The layout map is located at the lower center of the Title Sheet. Reference the layout map from the county maps directory. Urban and county maps are MicroStation design files. Urban Maps have a URB extension and County maps have a CNT extension. The design team should only show the area necessary for the project, along with a north arrow indicating the orientation of the map with true north (typically toward the top of the page). The map should not remain referenced to the Title Sheet file, as it is too large a file. Copy the portion of the map that shows the project onto the Title Sheet. Layout maps for urban area work should show enlarged views of the urban areas affected.

   The layout map should clearly show the following:

a. The location of the project roadway (with the project limits identified as “THIS CONTRACT”), nearby townships, ranges, section numbers along the route, existing roadways, the county name, towns, major drainage features, State-optioned borrow and surfacing sources, and railroads;

b. The beginning and ending stations of the project and project number;

   i. Station limits of any project connections beyond the beginning of project and end of project.

c. The construction project numbers and stations of referenced as-built projects;

d. Beginning and ending reference posts;

e. Signed route numbers for U.S., State, and local highways;

f. The name of the Indian reservation, when any portion of the project is located within the boundaries of a reservation;

g. Separation structures and bridges on the project. A single station number and reference post (R.P.), based on mainline stationing, will represent the approximate center of each structure. Data will indicate the length of each structure, whether it is an overpass or underpass in relation to the mainline and whether it will be constructed under this contract; and

h. Do not show non-optioned surfacing or borrow pits on the layout map or elsewhere on the Title Sheet.

8. **Related Projects.** Provide a block for related projects in the lower left-hand corner of the sheet. "Related Projects" are the project construction numbers of any projects that are tied to the project for letting. If there are no tied projects, the “Related Projects” block can be deleted.

9. **Associated Project Agreement Numbers.** Provide a block to show the associated project agreement numbers for right-of-way (R/W), incidental construction (IC), and preliminary engineering (PE) for the project.

10. **Project Approval Block.** A project approval block will be shown in the lower right-hand corner of the sheet. The approval block should include:

    a. the contract plan approval date;

    b. the Director’s name;

    c. the Highways Engineer’s or the Consultant Engineer’s (in responsible charge of the project) professional registration stamp; and

    d. when appropriate, the Federal Highway Administration (FHWA) Division Administrator’s approval.

Section 12.1.1 provides the proper order for listing, numbering and prefixing the plan sheets.

12.3.2 Table of Contents Sheet

Include a table of contents sheet in each construction plan set. The notes and linear and level data may also be placed on the table of contents sheet if sufficient room is available. If on the same sheet, each group of information must be clearly labeled "TABLE OF CONTENTS," "NOTES," and "LINEAR AND LEVEL DATA" and be placed in order from left to right, respectively.

The table of contents will indicate the major groups of sheets and those subgroups necessary to facilitate locating each item in the plans. Section 12.1.1 provides the proper order for listing, numbering and prefixing the plan sheets.

12.3.3 Notes Sheet

Include a notes sheet in each set of construction plans, or place the notes on the table of contents sheet (see Section 12.3.2). Notes provide general information necessary for plan users to obtain a complete understanding of the plans. Notes should not be used where subjects are addressed in the Standard or Supplemental Specifications or Special Provisions. Examples of information that may be addressed include:

1. Basis for plan quantities of surfacing materials;
2. Descriptions of items to be removed by non-contractor personnel;
3. Instructions for the contractor regarding items not to be disturbed;
4. Descriptions of work items absorbed in the cost of other bid items (e.g., clearing and grubbing);
5. Instructions for interpreting the plans; and
6. A skew diagram, if applicable.

12.3.4 Linear and Level Data Sheet

Include a linear and level data sheet within each set of construction plans, or place the linear and level data on the table of contents sheet (see Section 12.3.2). Linear and level data sheets will show a summary of project lengths, a tabulation of bench mark data (if provided), the sources of bearing and level data, and centerline coordinate table. The linear and level data should contain the following information:

1. **Project Lengths.** Summarize project lengths by showing paved roadway lengths, bridge lengths and total lengths for each of the following (does not apply to non-roadway improvements):
   a. Each route,
   b. Two-lane sections,
   c. Four-lane sections,
   d. Other multi-lane sections (including climbing and passing lanes; does not include auxiliary lanes such as turn lanes)
   e. Sections in different counties, and
   f. Areas not included in the contract but within the project limits (this does not apply to projects that include spot improvements at a number of sites, such as guardrail upgrades on multiple routes).

   Where there is a transition from a segment with fewer lanes to a segment with more lanes, the length of the transition is included in the segment with narrower lanes (e.g., for a transition from a two-lane to a four-lane section, the length of the transition is included in the length of the two-lane segment).

Connections that are located outside of the project limits are not included in the linear data.

Provide bridge lengths for bridges that are within the project limits. If no work is being performed on the bridges, then label as "NOT THIS CONTRACT". Bridge lengths are measured from the centerline of bearing to the centerline of bearing of the end bents. Formats of length summaries should clearly identify the sections for which individual lengths are shown (e.g., two-lane/four-lane and each county). Calculate the lengths in feet to two decimal places (e.g., 0.01 feet).

2. **Bench Mark Table**. For projects having control, the Z-coordinates of the control points can be used as the vertical control. Where these coordinates are available, the bench mark table is not required. Bench mark tabulations should show the station, location, description, and elevation of each bench mark. Show bench mark locations referenced to the mainline first, followed by bench marks referenced to other lines in the order they appear along the mainline.

   Clearly identify the road or line to which a group of bench marks is referenced. Tabulate each group of bench marks in the order of increasing stations. Show elevations, in feet, to two decimal places (e.g., 0.01).

3. **Bearing Source**. State the source used to take the bearings.

4. **Level Datum Source.** A detailed description will be provided to identify the level datum source. The description should include the bench mark location, elevation, number and any other pertinent information.

5. **Centerline Coordinate Table**. The coordinate table should show the station, description, northing or Y coordinate, easting or X coordinate, and any appropriate remarks. Show the coordinates to three decimal places (e.g., 0.001 feet). Coordinates are typically provided for:

   a. The project's beginning and ending points of the mainline and at connections, side roads, or any other splits described in Item #1;
   b. Point of Curvature (PC);
   c. Point of Intersection (PI);
   d. Point of Tangency (PT);
   e. Tangent to Spiral (TS);
   f. Spiral to Curve (SC);
   g. Curve to Spiral (CS);
   h. Spiral to Tangent (ST); and
   i. Station equation points.

12.3.5 Control Diagram

The control diagram is used to establish a permanent, recoverable horizontal and vertical control system for highway design and construction. All topographic features, section corners, controlling property corners, geological data, hydrological data, existing right-of-way, and miscellaneous design information are tied to the control. The control will also be used to layout the design centerline and right-of-way. During construction, if a control point is destroyed or becomes unusable, a new control point can be set using the control diagram. The following items should be considered when preparing the control diagram:

1. **Scale**. The diagram will be drawn using an appropriate scale, so that the diagram will fit onto one sheet.
2. **Segments.** The diagram can be broken into segments on the sheet to allow for a better fit.
3. **Standard Control Note (State Plane Projects).** Include the standard control note.
4. **Identification Number.** Show the control point identification number next to the control point.
5. **Congested Areas**. In congested areas where the control points plot close together, provide a detail, which does not need to be to scale, to show the relative positions and lines of sight.
6. **Symbol.** Plot control points using CADD standard symbols.
7. **Abstract.** The control diagram will require an abstract summarizing the important aspects of the survey control points. If practical, the abstract should be placed on the same sheet as the diagram. The abstract may be placed on a separate sheet and should contain:
   a. The point identification number;
   b. The northing or Y coordinate, rounded to three decimal places (e.g., 0.001 feet);
   c. The easting or X coordinate, rounded to three decimal places (e.g., 0.001 feet);
   d. The point elevation or Z coordinate, rounded to two decimal places (e.g., 0.01 feet); and
   e. A description on how to find or reach the control point.

12.3.6 Typical Sections

Typical sections are used to illustrate the cross section for a roadway surfacing section, the basis for surfacing quantities, roadway widths for tangent and superelevated sections, and cut and fill slope rates. Provide a separate typical section for each of the following situations:

1. Tangent sections;
2. Superelevated sections;
3. Where there are changes to the pavement structure;
4. Where there are changes from a curbed section to a non-curbed section;
5. Other typical sections not included with the mainline (ramps, cross roads, and frontage roads);

6. Cross section changes (e.g., shoulder additions, median changes); and
7. Where the bridge width differs from the roadway, provide a typical section matching the bridge roadway width from the end of the bridge to the end of the longest run of guardrail.

Changes in pavement width are generally shown on separate typical sections. For extremely localized changes in pavement width (e.g., turnouts, chain-up areas), the change may be shown on a detail with the additional quantities included in the appropriate frames. Separate typical sections are recommended when transitioning from a reconstructed or new section to an existing section or connection to present travel way (PTW) to ensure that adequate taper rates are provided. The need for a separate typical section for connections will be determined on a case-by-case basis. For these connections, the widths of the design and existing typical sections should at least be noted in the "Remarks" column of the Additional Surfacing summary.

Prepare typical sections using the following guidelines:

1. **Orientation.** Orient all typical sections horizontally (landscaped) on the sheet.
2. **Scale.** Draw typical sections using a scale of 1:120 (1″=10′), both horizontally and vertically. A different scale may be used for wide typical sections (e.g., four-lane highways).
3. **Order.** Show the mainline typical sections in order of increasing stations. If typical sections other than mainline are included, place them after the mainline sections in the order they appear relative to increasing stations along the mainline.
4. **Titles.** Number each typical section sequentially as they occur in the plan and profile sheets. The first typical section on a project should be No. 1, the second No. 2, and so on. If applicable, include the name of the road/ramp to which the typical section applies directly below the typical section number.
5. **Frontage/Access Roads**. Reference the beginning and/or end of frontage and access roads with respect to the mainline stationing.
6. **Station Limits.** List the station limits for which the typical section applies in the upper right-hand corner of each typical section. Station limits should also be included for bridge ends. The limits should extend from centerline of bearing to centerline of bearing of the end bents for each bridge. Transitions from one typical section to another should be stated next to the station limits (e.g., TRANS. TYP. 3 TO TYP. 4). Include the transition note on the preceding typical section. Transition call-outs are generally required at all typical section changes that occur over a distance. Where transitioning from a tangent section to a superelevated section, the transition stationing begins at the beginning of the tangent runout and ends where full superelevation is achieved, not at the PC, PT, TS, or ST. The station limits for superelevated sections should be followed by the appropriate superelevation and direction of curve (e.g., 7% RT). Where there is no transition distance between typical sections, such as where the roadway changes from a curbed section to a non-

curbed section, the next typical section number should be noted in the typical section station limits (e.g., THEN TO TYP. NO. 5).

7. **Cross Section.** The typical cross section view should show the following elements:
   a) The grading template, including cut and fill slope designs;
   b) Profile grade line reference;
   c) Surfacing templates, including surfacing type and thicknesses shown to the nearest 0.01 feet;
   d) Dimensions from which cuts and fills are staked; and
   e) Slopes and dimensions necessary to define the typical section. Use dimensions instead of slopes wherever the typical section can be defined with dimensions. Roadway cross slopes should typically be shown to the nearest percent (e.g., 2%). For typical sections beginning or ending within a superelevation transition area (instantaneous typical section), show cross slopes to the nearest hundredth of a percent (e.g., 0.01%). Show subgrade widths and intermediate widths to the nearest 0.1 foot.
8. **Slope Table.** Include fill and backslope tables where variable slopes are presented on the typical section.
9. **Quantities Frame.** Show the quantities of surfacing materials represented by the typical section underneath the typical section drawing. Superelevated sections that have the same top width and pavement structure as a tangent section typical section should reference the appropriate corresponding tangent typical section for quantities, if available. If the superelevated typical section represents most of the project, such as a curve reconstruction project, a quantities frame should be included with the superelevated typical section, and calculated based on the dimensions shown in the superelevated section. Section 13.5.2 provides the rounding criteria that should be used in the quantity frame.
10. **Width Table (For Superelevated Section).** A width table showing the roadway widths should be provided for each superelevation rate for a given typical section, if multiple superelevations are required. Where only one superelevation rate occurs for a typical section, show the dimensions within the typical section, in the same manner as for a typical section of a tangent roadway section. Exhibit 12-1 illustrates a sample width table.

Exhibit 12-1
Sample Width Table

SUPER.	WIDTHS (feet)						
%	A	B	C	A’	B’	C’	D’
5	18.6	19.9	25.9	17.4	18.1	22.7	3.2
7	19.1	20.7	25.9	17.3	17.9	22.1	3.8

Note: C’ + D’ = C

11. **Notes.** The R-values of the subgrade material, which are the basis for surfacing design, will be shown on the typical section. Design and construction notes that are only pertinent to the specific typical section may also be included on the typical section.

12. **Special Borrow**. When special borrow is provided in the surfacing recommendations from the Surfacing Design Section, it can be designed into the typical section as an additional layer of material, or it can be designed as the top component of the subgrade. When special borrow is designed into the typical section, the subgrade shown on the cross sections is located at the bottom of the special borrow.

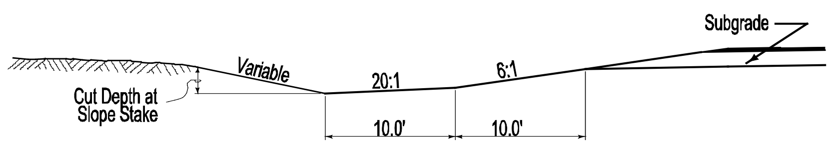
    When special borrow is designed as the top 2 feet of the subgrade, it should not be shown in the typical sections. However, in cut sections where the subgrade inslope is 6:1, the subgrade inslope is typically extended from 10 feet to 14 feet to ensure that the bottom of the special borrow is above the ditch. The following options need to be evaluated for the treatment of the flat-bottom ditch:

    a) Provide the entire 10-foot flat-bottom ditch, or

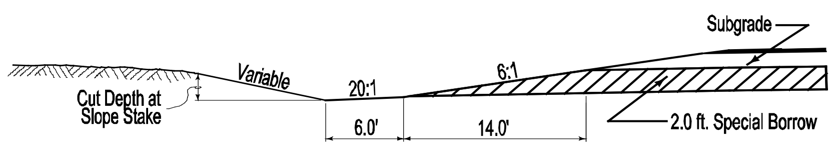
    b) Reduce the ditch width to 6 feet so that the hinge point of the backslope is at the same offset as it would be for the same typical section without special borrow in the subgrade.

    Exhibit 12-2 provides an example for the ditch section adjusted for special borrow.

Exhibit 12-2
Ditch Section Adjusted for Special Borrow



Standard Ditch Section



Ditch Section Adjusted For Special Borrow

When a 4:1 subgrade inslope is used (such as for low-volume secondary routes), the special borrow will daylight within the 10 feet inslope, and no adjustment is necessary.

When the special borrow is included in the subgrade, either as a surfacing recommendation or to address site-specific subsurface conditions, it should be shown in a detail. Local applications of special borrow at the top of subgrade are also represented as hatched areas on the cross sections and in the profile.

The decision on how to apply special borrow recommendations should be documented in the Alignment and Grade Report.

12.3.7 Summary Sheets

One or more summary sheets will be included in each set of construction plans. Summary sheets show all quantities required by the plans. No other data will be shown on the summary sheets. Chapter 13 presents the guidelines for developing plan quantities. Prepare the summary sheets according to the following guidelines:

1. **Summary Frames**. MDT's CADD standards directory includes a quantity management spreadsheet used for creating the frames that show and summarize plan quantities. Once created in the spreadsheet, image links of the individual summary frames are copied into the CADD summary sheet files.
2. **Frame Adjustments**. The most commonly used summary frames are included in the default frames folder; however, the summary frames may need to be adjusted for the project. When developing a summary frame that is not included in the default frames, start with a similar default frame and modify it in the spreadsheet to the format shown in the sample plans. The frames should include three blank rows between the last quantity and the total. Additional rows may be required for large projects. To eliminate possible confusion, blank out or remove unused columns within the frame.
3. **Stationing.** Stationing within each summary frame should be sequential wherever practical. *MDT Sample Plans* provide the recommended station listing procedure that should be used within each frame.
4. **Rounding**. Appendix J presents the rounding procedure that should be used within each summary frame.
5. **Separate Frames.** Separate frames may be required for the same items when more than one funding is used on a project. For more information on when separate frames should be used, see Chapter 13.

12.3.8 Hydraulic Data Summary Sheet

The hydraulic data sheet contains the information on culvert sizes greater or equal to 30 inches, bridges, longitudinal encroachments, flood data, and other necessary hydraulic data. When optional culverts are used, the base bid option will be shown in the summary sheet. This sheet is prepared by the Hydraulics Section. The design team is responsible for incorporating it into the plans.

12.3.9 Detail Sheets

12.3.9.1 General

Detail sheets are used for those items that require more specific information than can be adequately described on either the plan or the profile views of the plan and profile sheets. Detail sheets are used to show:

1. Drainage details, including storm drains, special ditches (PESC);
2. Miscellaneous details, including details for major approaches, intersections, interchanges, connections to existing pavement, and others;
3. Geometric details, or other plan sheet type details;
4. Standard details that are not detailed drawings;
5. Any other detail necessary that is not included or is modified from the detailed drawings;
6. Special maintenance and protection of traffic through construction zone details; and
7. Mass diagrams (not included in final construction plans).

Clearly label each detail in the title box in the lower right-hand corner of the space allotted to the detail. In the title box, show the name of the detail, the station(s) to where it applies and the scales to which it is drawn, if appropriate. Some details are intended to show a closer view of specialized work in an area, which may require some scaling of surveyed or designed features that are represented with symbols. For these cases, the best practice is to draw the existing or proposed features as accurately as necessary for the work represented in the detail, and use text instead of standard symbols to identify features.

Arrange the detail sheets such that multiple details of the same type are together in the plans (e.g., all storm drain details on sequential pages). The order of the details within each group should follow the order the item or location is encountered in the direction of advancing station along the design centerline.

12.3.9.2 Plan Sheet Details

These sheets may be used for special cases involving extensive additional work. They will use the same format as the plan sheets described in Section 12.3.10.4, but for clarity reasons, will not include quantities listed on the plan sheet. Plan views of geometric layouts are used where the mainline plan and profile sheets cannot adequately show horizontal alignment details of large or complex facilities, such as major intersections. The contents of geometric layouts generally should be the same as the contents of plan views on mainline plan and profile sheets, except that the topography will not be shown and the name of the features should be clearly shown on the right side of the detail.

The design speed for each crossover or detour should be shown in the title block in the lower right corner of the sheet.

12.3.9.3 Temporary Detours and Median Crossovers

The need for separate details for maintenance of traffic through the construction zone will vary from project to project. For crossovers or temporary detours, show the plan and profile views, detour typical section, detour centerline coordinates, and items of work included in the traffic control feature on a detail sheet. The design speed for each crossover or detour should be shown in the title block in the lower right corner of the sheet. Profile views and centerline coordinates may not be necessary for crossover installations for narrow medians. For detours that include temporary drainage culverts, include the following:

1. Plan and profile of the detour. It is recommended that the low point on the detour is located at least 75 feet from the culvert;
2. A profile detail of the culvert installation including elevations;
3. Cross section(s) showing the culvert invert elevations, the location of the geotextile placed on the embankment faces, and the location and extent of either: the drain aggregate, geotextile or hay/straw placed in the stream channel;
4. Quantities of drain aggregate, geotextile, and hay/straw in the items of work.

Typically, a lump sum bid item should be used to construct, maintain, and remove detours. For crossovers and projects with more than one detour, these features are generally bid by each installation. For either case, the items of work shown on the detail should be identified as "FOR INFORMATION ONLY" and not included in other itemized project quantity summaries or estimates. Section 13.6.1 provides additional information on lump sum bid items.

12.3.9.4 Mass Diagrams

A mass diagram detail sheet is included in the preliminary construction plans for larger projects using unclassified excavation. Mass diagrams are not required for embankment-in-place projects, smaller excavation projects where haul is not a concern, or urban projects. The mass diagram provides an overall view of the earthwork quantities and how they could be moved. See Section 13.3.4 for more information on mass diagrams. Scale the mass diagram so that it can be placed onto one page. Where practical, the mass diagram should be continuous with no breaks. The mass diagram should contain the following information:

1. Begin and end stations with the project number;
2. Mass curve and balance line;
3. Balance point station, to the nearest foot;
4. Volumes of unclassified excavation and embankment between balance points;
5. Borrow or excess volumes, if applicable;
6. Shrink/swell factor(s);
7. A scale for horizontal and vertical units; and
8. A note at the bottom of the sheet that says "Note: This mass diagram is for information purposes only. It represents one possible approach to performing grading on this project."

Section 13.3.4 provides additional information on how to use a mass diagram.

12.3.10 Plan and Profile Sheets

The plan and profile sheets are the basic design sheets used by the design team to illustrate the horizontal and vertical alignments and to depict the construction items and the topography necessary for construction. Therefore, these sheets need to be drawn with clarity and be as simple as practical but still provide the necessary information to construct the project.

12.3.10.1 General Guidelines

The following provides several guidelines for the preparation of the plan and profile sheets:

All vertical notes and labels should be oriented to read from left to right when viewed from the right side of the plan.

1. **Views.** It is preferred to provide the plan and profile on the same sheet. The plan view is shown in the upper half of the sheet with the corresponding profile view shown directly below it with the stations in each view lining up.
2. **Sequence of Sheets.** Show the mainline plan and profile sheets first, in the order of increasing stations. Project stationing typically increases from south to north and west to east. Do not interrupt the continuous stationing of the mainline plan and profile sheets with the insertion of plan and profile sheets for other facilities (e.g., side roads, frontage roads, railroads). Insert these additional plan and profile sheets after the mainline sheets in the order they appear along the mainline.
3. **Labeling.** Clearly label all additional plan and profile sheets on the top of the sheet so that the plan user can readily determine what plan and profile is being shown.
4. **Sheet Overlap.** There should be no sheet overlap between successive sheets (i.e., use match marks). Generally, lay out the sheets so that approximately 3,000 feet of the project is shown on each sheet.
5. **Note Orientation**. In general, write all notes and dimensions horizontally on the sheet from left to right, except for the following:
    a. **Plan Views.** Pipe, irrigation facilities, bridges and storm drain installation notes are placed vertically at the bottom of the plan view. Stationing, at 1,000-foot intervals, is placed parallel and/or radially above the centerline. Curve data is placed radially on the inside of the curve. The curve station callouts should be placed on the left side of the leader because right-of-way data is always placed on the right side of the leader. Place curve controls, equations, and angle points at right angles to the centerline.
    b. **Profile Views.** Write equations diagonally. Full stations and elevations of Vertical Points of Intersection (VPIs), pipe stations, begin/end stations and bridge end stations should be written vertically. Horizontally place any notes above the profile.
    c. **Special Considerations.** Where limited space for notes and dimensions makes horizontal placement detrimental to the readability of the plans, they may be placed vertically or below the profile.
6. **Use of Notes**. Notes on plan sheets should be brief, clear, and consistent. Indicate any installations and removals by station and provide a brief description. Do not include detailed descriptions on the plan and profile sheets. These should be placed on the Note Sheet. Typical notes for some common items are shown in Exhibit 12-3.

Exhibit 12-3
Typical Plan and Profile Notes

Item	Typical Note
New culvert (optional)	65+00 NEW 24” DR.
New culvert (non-optional)	65+00 NEW 24” CSP DR.
Existing culvert to be removed	70+30 24” CMP IN PL. REMOVE
New approach	75+20 PUBLIC APP. RT.
New riprap	92+35 TO 93+80 CL. 2 RIPRAP RT.
Subexcavation	82+00 TO 83+30 SUBEXC.

7. **Drafting Details**. The *MDT Detailed Drawings* provide the recommended abbreviations that should be used. Section 12.2 also provides additional drafting details that should be reviewed when preparing plan and profile sheets. Items that are drawn on the strip map should typically be located and scaled as accurately as possible. Culvert ends should accurately reflect their locations and direction of flow, though the culvert width may be exaggerated for clarity. Similarly, items such as manholes, telephone pedestals, signs, or other items represented by symbols should be located as accurately as possible but scaled such that the symbol can be clearly identified when the plans are printed. Approach widths and catch points should be drawn accurately to help identify potential impacts to private property, utilities, and other roadside or environmental features.
8. **Approaches.** Correct approach designations are required for right-of-way purposes. However, during design it may be difficult to determine the appropriate designation (e.g., private or farm field). The design team should use their best judgment to designate approaches during design. When right-of-way agreements become available, the design team should check the agreements for providing the appropriate approach designations in the plans. The following defines the various approaches and example plan notations are shown below.
   a. **Public Approaches.** Public approaches are connections to/from a highway, street, road, alley, or dedicated public right-of-way.
   b. **Private Approaches.** Private approaches are entrances to/from a commercial, industrial, or residential property.

c. **Farm Field Approaches.** Farm field approaches are revocable entrances to/from a field for agricultural purposes.

PUBLIC APP.
PRIVATE APP.
PRIVATE APP. (JOINT)
FARM FIELD APP.

Example:
100+20
PRIVATE APP. LT.

d. **Widths.** Approach widths other than 24 feet should be noted on the plan sheets (see example below) and cross sections. For urban projects, show all approach widths.

Example:
20+00
FARM FIELD APP. LT.
32′ TOP

12.3.10.2 Plan View

The following presents the recommended guidelines for preparing the plan view:

1. **Centerlines.** Only the design centerline is shown in the plans.
2. **Horizontal Alignment Data.** Chapter 3 presents the design criteria for the horizontal alignment. Show the horizontal alignment data in the plans as follows:

   a. **Horizontal Curve Data.** Place horizontal curve data, including superelevation, inside the curves to which they apply. When a curve extends onto multiple sheets, show the curve data on the sheet where the PI is located. Exhibit 12-4 presents the order and rounding accuracy that should be used to present the curve data.

Exhibit 12-4
Horizontal Curve Data (Plan Sheets)

Spiral Curve Data	Simple Curve Data	Accuracy
Δ	Δ	00° 00’ 01”
R (existing)	R (existing)	0.01 feet
R (new)	R (new)	10 feet
L_S		0.01 feet
Θ_S		00° 00’ 01”
Δ_c		00° 00’ 01”
Ts	T	0.01 feet
Lc	L	0.01 feet
Es	E	0.01 feet
S	S	1%

b. **Curve Points.** Show perpendicular lines from the design centerline for all curve points. Indicate the curve notation (e.g., PC, PT, SC, TS) and station, to the nearest hundredth of a foot (e.g., 0+00.01) along the perpendicular line. Include the PI station with the curve data.

c. **Bearings.** Write bearing notations below the line to which they apply. Note the bearing in degrees, minutes, or seconds, rounded to the nearest second (e.g., 00° 00′ 01″).

d. **Offsets.** Where multiple centerlines used (e.g. ramp termini), note the offset from the mainline to the auxiliary centerline at the beginning and end points where they are parallel to each other.

e. **Equations.** Equations are used to correct a discrepancy in stationing that may occur along the centerline. Show them perpendicular to the design centerline similar to that discussed in Item "b" above. For more information on equations see Chapter 3.

3. **Topography.** The topography shown should include all utilities, irrigation and drainage facilities, buildings, and other items pertinent to construction. In general, show existing elements as grayscale solid lines and proposed elements in dashed lines that are not grayscale. Existing utilities are shown using the appropriate line codes and symbols. Include the north arrow, along with the township and range, on all plan sheets and ensure that it is consistent from sheet to sheet. Also list the section with the north arrow unless section corners or section lines are shown on the sheet.

4. **Items to be Removed or Abandoned**. Show all items within the right-of-way limits that will be removed or abandoned in place. Clearly note those items that will be removed by non-contractor personnel.

5. **Station Call Outs**. Provide station call outs at the following locations:

   a. Beginning and ending points of the project;

   b. Increments of ten stations (increments of five station increments for 1″= 40′ scale urban projects);

   c. Horizontal curve points;

   d. Beginning and ending points of tapers, including the distance and direction from the design centerline (not necessary if information is provided in a detail);

   e. Construction permit locations and right-of-way breaks;

   f. Curb openings, including the curb opening width and direction from the design centerline;

   g. Curb ramp locations, including the direction from the design centerline;

   h. Drainage crossings, inlets, grates, manholes, water valve boxes, sewer crossings, and where applicable, the distance and direction from the design centerline;

   i. Utility crossings;

For some of these features, callouts that appear on separate details (e.g., storm drain plans) are not called out on the plan and profile.

j. Side street intersections;

k. Monument boxes, including the distance and direction from the design centerline;

l. Section line ties, right-of-way takes, including the distance and direction from the design centerline; and

m. Other locations where deemed appropriate (e.g., county line, urban to rural change, two-lane to four-lane change, reservation boundary).

Note: For Items e, k, and l, items shown on the Right-of-Way Plans may be excluded from the Road Plans, if necessary, for plan clarity. If right-of-way elements are removed, add a note to plan sheet(s) that states, "See Right-of-Way Plans for right-of-way design elements."

6. **Drainage.** Show all drainage structures in the plan view including culverts, bridges, and storm drainage systems. Sanitary sewers and water mains should be considered as utilities; these are described in Item 7 below. The following presents several guidelines for placing drainage structures on the plan view:

   a. **Culverts.** For culverts or cross drains note the station location, the pipe size, skew angle, and flow direction. Round skew angle to the nearest degree. For new installations, unless directed otherwise by the Hydraulics Section, the culvert material type will be at the contractor's discretion and should not be noted on the plans. Note the material type when it is specified by the Hydraulics Section and for existing culverts to be removed, lengthened, or remain in place.

   b. **Bridges.** Bridges should be shown on the plan sheet with centerline station locations of the removed bridge and the new bridge. General bridge details are shown in the profile view. Detailed design information will be provided in the bridge plans.

   c. **Storm Drains.** Storm drainage systems are provided on the plan view using the line symbols as shown in the MDT CADD Standards. Include the pipe size and type next to the topography symbol. Note all inlets, outlets, and manholes; list them according to work description (e.g., NEW MANHOLES, RESET INLETS, PLUG AND ABANDON EXISTING MANHOLES). On projects with substantial storm drain work, provide separate storm drain plan and profile type details with all new storm drain items shown and called out. The only storm drain items noted on the Plan and Profile sheets are existing storm drain items to be removed or modified. The listing should include the station location and the distance and direction from the design centerline.

7. **Utilities**. Where overhead utilities cross the centerline, include notes to indicate the design centerline station, the type of utility, the number of wires, and the clearance above the existing ground. Where underground utilities cross the centerline, include notes to indicate the design centerline station, the type of utility, and the size and depths of the utility below the existing ground. If these elevations are not known, they

should be called out as "DEPTH UNKNOWN" or "CLEARANCE UNKNOWN".

Provide a listing of the valve boxes or utility manholes shown in the plan view on each plan sheet. Organize this listing according to the type of work (e.g., "ADJUST MANHOLES IN PLACE"). Under each heading, the listing should include the station location and the distance and direction from the design centerline.

8. **Construction Limits**. The limits of construction are shown on the plan view and are the basis for identifying the needed right-of-way required for the project. They are also used to identify construction conflicts with existing utilities, wetlands, or other significant features within the corridor
9. **Right-of-Way**. The right-of-way plans will:
   a. Show the right-of-way limits on the plan view;
   b. Note any breaks in the right-of-way alignments by the design centerline station and offset distances;
   c. Show any easements, construction permits, and control of access limits, as applicable; and
   d. Clearly label each line where the control of access limits do not coincide with the right-of-way limits.

   The bearings of the section lines, township lines, and range lines crossing the design centerline should be clearly shown, as should the station at the point of intersection. Do not use angle call outs.

   Label section lines with the appropriate section numbers. If section lines are not present, show the section number below the north arrow.
10. **Guardrail.** Show the locations for new and existing guardrail on the plan view.
11. **New Curb and Gutter**. Show locations of new curb and gutter on the plan view. Where applicable, provide a note on each plan sheet listing the stations, widths, and direction from the design centerline for each curb opening located on the sheet.
12. **New Sidewalk.** Show the location of new sidewalk to scale on the plan view. Where applicable, provide a note on each plan sheet listing the stations and direction from the design centerline for each curb ramp located on the sheet. Most curb ramps will require additional details.
13. **Monument Boxes.** Where applicable, provide a note on each plan sheet listing the stations, distance, and direction from the design centerline for each monument box located on the sheet.
14. **Wetlands.** Delineate wetlands and wetland impacts. Identify the delineated wetlands with a hatching and areas with wetland impacts with a cross-hatching.
15. **Core/Bore Logs.** Place the appropriate symbol to indicate the core/bore log location on the plan sheet.

12.3.10.3 Profile View

The following presents the recommended guidelines for preparing the profile view:

1. **Scale.** The horizontal scale of the profile should match that of the plan view, and the vertical scale is ten times the horizontal scale. For rural projects this would result in a 1″= 200′ horizontal scale and a 1″= 20′ vertical scale. For urban projects this would result in a 1″= 40′ horizontal scale and a 1″=4′ vertical scale. The profile can be split vertically in areas where there is a large elevation change as necessary.
2. **Existing Ground Line.** Show the existing ground line along the design centerline for each profile view as a solid line. See the *MDT CADD Standards* for the applicable line weights.
3. **Vertical Alignment Data.** Chapter 4 presents the design criteria for the vertical alignment. The vertical alignment data should be shown in the plans as follows:
    a. **Profile Grade Line.** The profile grade line represents the elevation of the top of the finished surfacing at the location shown in the typical sections. In superelevated sections, when the typical section defines the profile grade point less normal crown, the profile grade line represents the theoretical elevation of centerline at normal crown.
    b. **Vertical Curve Notations.** Depict the Vertical Point of Curvature (VPC) and Vertical Point of Tangency (VPT) with small circles on the profile grade line. The small circle for the Vertical Point of Intersection (VPI) should be shown with short segments of the tangent grades. Note the VPI station to the nearest hundredth of a foot (e.g., 0+00.01) and elevation to the nearest hundredth of a foot (e.g., 0.01) on the profile view. Place VPI notes vertically above the profile for crest curves and below the profile for sag curves. Do not record the VPC and VPT stations and elevations on the profile view.
    c. **Vertical Curve Lengths.** Round the vertical curve calculations determined from Chapter 4 to at least the next highest 50 feet increment for new vertical alignments and to the nearest 0.1 feet when matching the existing alignment. Write vertical curve lengths horizontally above the profile for sag curves and below the profile for crest curves.
    d. **Tangent Grades.** Show tangent grades to the thousandth of a percent (e.g., 0.001 %). Show positive grades with the "+" prefix and negative grades with the "−" prefix. A "+" prefix indicates that the grade is ascending in the direction of stationing.
    e. **Transition Grades.** Sections using transition grades (spline grades) should be noted as “Transition Grade”.
    f. **Begin/End Stations and Elevations.** Label the profile grade line at the beginning/ending project stations to the nearest hundredth of a foot (e.g., 0+00.01) and elevations to the nearest hundredth of a foot (e.g., 0.01).

   g. **Bridge Stations.** If the project contains a bridge, label in the profile view the centerline bridge end bent stations to the nearest hundredth of a foot (e.g., 0+00.01) and centerline proposed finished grade elevations to the nearest hundredth of a foot (e.g., 0.01).

4. **Curb and Gutter Profiles.** Where curbing is provided, a supplemental profile will be required that shows the profile at the top back of curb regardless of whether or not the curb grade is parallel to the centerline grade. Provide a gap in the profile for each curb cut. The criteria presented in Item 3 also apply to curb profiles. Show the existing ground line on each profile. Show the left-curb profile on the top of the profile view and the right-curb profile on the bottom.
5. **Curbing/Sidewalks**. Where curbing and/or sidewalks are provided, draw a straight, horizontal line on the bottom portion of the profile view from radius point to radius point for each curb and/or sidewalk location. Show curbing and sidewalks for the left side on the top and those on the right side on the bottom. Record the sidewalk information including type, location and radii on the top of the line. Curb information including type, location, and radii are provided below the line. Show all dimensions for curbs to/from the back of the curb and not the face of curb.
6. **Subexcavation.** Show subexcavation as a hatched area under the profile grade line. The subexcavation should be shown to the top of the subgrade and not to the profile grade line. Each subexcavation location should note the station locations. Show the width and depth of subexcavation on a detail sheet.
7. **Drainage Structures.** Show mainline cross drainage structures as ovals on the profile view and provide a plus station callout (e.g., for a pipe located at 20+35, show "+35" at the pipe symbol in the profile view). Show new cross drainage culverts as solid ovals and existing cross drainage culverts as open ovals. Longitudinal drainage structures are generally not shown unless there may be a potential conflict with utilities, or other drainage structures. Where conflicts may occur, provide a supplemental profile, unless it is already provided in a detail. Show bridges as a hatched area equal to the length and depth of the superstructure. Also show the riprap at bridge ends.
8. **Guardrail.** Show new guardrail locations on the profile view as straight, horizontal lines. Provide separate lines for each side of the road. Label the guardrail type above the line. Existing guardrail to be removed will be described in a note on the profile view.
9. **Vertical Clearances.** Show the vertical clearances for all overhead structures on the profile view. Record the minimum clearance distance to the nearest tenth of a foot (e.g., 0.1).
10. **Core/Bore Logs.** Show the elevation view of the core/bore log to scale with the thickness and soils classification of each soil placed at the correct elevation. Place the station, offset, and identification number at the bottom of the core/bore.

Consider the road superelevation and bottom of the structure to determine the minimum vertical clearance location on the facility.

11. **Supplemental Profiles Sheets.** Supplemental profile sheets may be provided as detail sheets to illustrate special drainage structures and roadside ditches.

12.3.10.4 Plan Sheets

Plan sheets provide only the plan view of the roadway and can be categorized into two formats. The design team should select one of the following formats depending on the work involved:

1. **Straightline Diagram Sheets.** These sheets are typically used for overlay projects having no right-of-way involvement. The horizontal alignment is represented by straight lines. Curves are not depicted but curve data is provided. Two or three segments of roadway may be shown on a sheet depending on available space. Scales other than 1:2400 (1″=200′) may be used. If more than one segment is included on a page, the segments should go from top to bottom of the page in order of increasing stationing.
2. **Plan Sheets.** These sheets are typically used for widening and overlay projects requiring right-of-way acquisition or construction permits. These sheets should use a 1:2400 (1″=200′) scale. They are similar to the ″plan" portion of plan and profile sheets. Information which is normally included on the profile may be shown on these sheets (e.g., guardrail). Two segments can be included on each sheet if enough room is available for all notes.

12.3.11 Preliminary Plans

The plans package is considered preliminary until it is completed, checked, and submitted to the Contract Plans Bureau. Every page is identified as "Preliminary" in the title block throughout the design process. The following represents the condition of the plans at the milestone events throughout the design process.

12.3.11.1 Alignment and Grade Review

The plans are considered about 30 percent complete at the Alignment and Grade Review (AGR) stage. This is the first formal review of the project with all design team members and plans showing proposed features. The review focus is on the proposed mainline surfacing, horizontal and vertical alignments, and grading. These elements of design constitute the bulk of the project footprint and cost, and they should be reviewed to meet the project purpose and need while balancing or minimizing impacts and costs. It may be appropriate to review alternate alignment and surfacing options at the AGR; in these cases, multiple sheets or plan sets may be reviewed.

The plans should include items identified 1 through 10 in Section 12.1.1.1, and described above, with the following exceptions:

- The Table of Contents should identify anticipated project summary frames; however, only the Surfacing and Grading frames showing mainline quantities are typically needed for the AGR.

- Detail Sheets are generally not included at the AGR, although preliminary details for items that act as control points or that have significant impacts as a result of the design alignments may be included (e.g., major drainage crossings or major intersections). Include a Mass Diagram Detail with mainline grading if appropriate for the project.
- Include all existing features and information identified by survey on the Plan and Profile sheets. Items that are impacted by the proposed construction limits, including utilities, wetlands, and existing right-of-way limits, need to be considered at the AGR. Major drainages and road approaches are labeled, although proposed items such as culverts, approaches, guardrail, etc. are not generally included at this time, unless their impacts are significant. If the proposed alignment is offset from the existing roadway, show and label the existing centerline profile as well as the ground line profile along the proposed alignment.
- Cross sections will typically only include the mainline grading template and existing features (e.g., existing culverts, right-of-way, and utilities). Proposed culverts and approaches are not typically shown for AGR unless they serve as horizontal or vertical control points, or have significant impacts associated with the proposed alignments.

Sample AGR plans are available at the following link on the MDT Website:

Sample AGR Plans (under construction)

12.3.11.2 Plan-In-Hand

The plans are considered about 85 percent complete at the Plan-In-Hand (PIH) stage, and the focus of the review is on completeness and accuracy of the plans, constructability, and minor changes that impact construction limits.

Include draft special provisions from all functional areas with the plans distribution for PIH. See Chapter 14 for information on special provisions.

The plan set should include all plan sheets needed for construction, as well as design of all elements that have impacts to the project construction limits. The following should be considered in preparing plans for PIH distribution, and for discussion at the review:

- Summary Sheets should be substantially complete, although some items may not be known at the time of the review. Fencing materials may not be known until the right-of-way negotiations are complete.
- If the project includes a Mass Diagram, be sure it is updated with all earthwork quantities. Consider if detail sheets are necessary for special design elements, extensive approach work beyond the right-of-way, or additional traffic control features.
- Make sure all approaches are shown to scale, and include construction limits for approach work that has utility, wetland, or right-of-way impacts beyond the mainline limits.

12.3.11.3 Final Construction Limits

Following the PIH inspection, complete all changes identified that affect construction limits first. Although there is not a formal meeting associated with the distribution of final construction limits, it is a significant milestone within the design process, and necessary for developing final right-of-way plans, environmental permitting, utility relocation and railroad construction agreements, and railroad crossing evaluation requirements.

When notification of final construction limits is sent, ensure the design map and plans have the following features:

- Show final proposed mainline construction limits on the strip map and Plan and Profile sheets. Include other permanent construction limits for approaches, separated paths, channel changes, etc., that extend outside of the existing right-of-way, or have impacts to wetlands or utilities. Include temporary construction limits for detours on a different level of the strip map.
- Show and label all utility crossings on the Plan and Profile sheets and cross sections.
- Provide areas of permanent and temporary wetlands impacts.
- Coordinate with the Rail/Highway Safety Unit and the Utilities Section when any of the following conditions exist:
    1. Railroad tracks cross the highway within the construction limits of the project.
    2. There is a railroad crossing on an approach road that is within 50 feet of the construction limits of the project.
    3. A railroad crossing is located where it may be affected by the construction traffic control for the project (e.g., traffic control may cause traffic to back up through a railroad crossing that is not within the project limits, or the use of a detour may increase traffic at a railroad crossing).

12.3.11.4 Final Plan Review

The plans package (plan sheets, cross sections, special provisions, and estimates from all design functional areas) should be complete for the Final Plan Review (FPR), as the focus of this review is finding errors and omissions within the plans. Prior to the FPR, ensure that all plans necessary for the project are completed and assembled. Ensure that all the road design plan sheets and cross sections include the latest right-of-way lines and callouts. Reconcile any differences in stations, materials, and quantities shown on the summary sheets with notes on the plan and profile sheets and cross sections. Similarly, reconcile the road plans with information provided in special provisions and other plan sets (e.g., bridge plans, signing and striping plans).

12.3.12 Cross Sections

Cross sections provide a graphical representation of the proposed roadway as compared to the existing ground line. The following sections present the general guidelines for developing cross section sheets.

12.3.12.1 General Considerations

The following presents general cross section considerations:

1. **Orientation.** Draw the cross section horizontally (landscaped) on the sheet. Show the cross sections from the bottom of page to the top according to increasing stations.
2. **Spacing.** Space the cross sections so that there is no overlap of the individual cross section exhibits, especially in areas of large cuts or fills. Align individual cross sections on a page vertically with the design centerline, or staked line where applicable.
3. **Intervals.** Plot the cross sections at 50 feet intervals in rural areas and 25 feet intervals in urban areas. Plot additional cross sections at major grade breaks, all pipe crossings, all approach centerlines, all curve control points (TS, SC, CS, ST), all typical section transition points, and other locations as deemed necessary. Plot additional cross sections at all superelevation control points for both simple and spiral curves (refer to Chapter 3).
4. **Order.** Show the mainline cross sections first, in increasing stations. Individual cross sections of approaches will generally not be shown, except in cases where major construction is conducted for a significant distance along the approach. For skewed culverts, cross sections taken along the skew of the culverts may also be included. Where cross sections for side roads, frontage roads, ramps, or skewed culverts are provided, place them after the mainline cross section in the order they appear along the mainline. Clearly label each special cross section sheet to allow the user to identify the location of the cross sections.
5. **Items Shown on Cross Sections**.
    a. Existing ground line;
    b. Proposed top of subgrade line (the finish top surfacing may be shown);
    c. Design centerline location (staked line if applicable);
    d. Station locations;
    e. Elevation of the top of subgrade at the design centerline, edge of subgrade, ditch bottoms, construction limits, and other appropriate break points, placed vertically, to the nearest 0.01 foot;
    f. Existing groundline elevation at the design centerline, or staked line if applicable, placed diagonally;
    g. Roadway slopes for both right and left of the design centerline and offset from staked line, if applicable;
    h. The actual amount of excavation or embankment between stations (no shrink or swell factors are applied), in cubic yards (excavation values are shown on the left and embankment values shown on the right);
    i. Right-of-way limits; and

j. The project number, street name, or other special cross section identification information.

12.3.12.2 Plotting Details

The design team may be required to plot the following elements on the cross sections:

1. **Drainage**. Drainage elements are commonly plotted separately on the cross sections. Section 12.3.12.3 provides additional information on how to present the drainage structures on the cross sections.
2. **Utilities**. Plot both overhead and underground utilities on the cross sections.

   In general, all underground utilities should be shown on the cross sections. Additional plotting may be required for all utility crossings. Also if available, include in a note the following additional information for various utilities:

   a. Gas meter: pipe diameter
   b. Gas valve: type (above or below ground) and pipe diameter
   c. Guy pole: type (anchor, push or other)
   d. Manholes: description (electric, storm, sewer or other), type (cone, straight, or other), depth, and diameter
   e. Pedestal base: type (electric, telephone or other) and size
   f. Power pole: type (wood, steel, laminated or other), pole number, and underground drop, if any
   g. Power pedestal: type (pole or ground mount) and box number
   h. Telephone pole: type (wood, steel, laminated or other), pole number, and underground drop, if any
   i. Telephone pedestal: type (pole or ground mount) and box number
   j. Water meter: pipe diameter
   k. Water valve: type (above or below ground) and pipe diameter
   l. Tower: type (communication, electrical, or other)
   m. Misc. valves: type (above or below ground) and pipe diameter

   Coordinate with the Utilities Section and with respective utility companies to confirm required clearances.

   For overhead utility crossings, place appropriate line(s) between the cross sections that graphically represents the utility crossing station. Place a note near the centerline of the crossing stating the station, type of crossing (power, telephone), clearance to lowest wire, and total number of wires.

   For underground utility crossings, place appropriate lines between the cross sections that graphically represent the utility crossing station. Place a note near the centerline of the crossing stating the station, type of crossing (gas, telephone, or sanitary sewer), the depth of the utility, and the diameter of pipe (if known).

3. **Grading Notes**. Show subexcavation locations on the cross sections. Show the total volume amounts with a note, along with any Geotextile

fabric that is to be installed. Special borrow that is included as a surfacing layer of the typical section is not shown on the cross sections.

Additional grading notes may be added to the cross sections to give direction to the contractor (e.g., "GRADE TO DRAIN").

4. **Structures.** Depict buildings, bridges or other structures affected by construction on the cross section sheets.
5. **Right-of-way.** Show the right-of-way limits on the cross sections for both new and existing right-of-way. Construction permits and easements will generally need to be plotted on the cross sections separately.
6. **Approaches.** Provide individual cross sections at the centerline station of each approach location. Show the approach subgrade and surfacing from the mainline shoulder extending to where the approach ties into the existing ground. Depict the approach landing and label the approach grade. Show the approach culvert as a circle drafted at the appropriate elevation and mainline offset, if applicable. Place a note on the cross section that includes the approach station, offset, and grading quantities.
7. **Miscellaneous.** Identify any other items that are included (e.g., ditch blocks, PESC, riprap drain, and concrete drain).

12.3.12.3 Drainage Structures

The following presents guidelines for showing drainage structures on cross sections:

1. **Culverts.** Provide individual cross sections for each pipe location. Culverts must be fully described on cross section sheets. Each description should include a drawing and a note or "callout." The sample cross section sheets provided in the *MDT Sample Plans* illustrate the procedures for noting culverts on the cross section. In addition, consider the following:
   a. **Mainline Culverts Without Skews.** Each culvert drawing should show the lines representing the top of the pipe, the flowline of the pipe, bedding, foundation material, and the appropriate end treatment.
   b. **Mainline Culverts With Skews.** Skewed mainline culverts should only be shown skewed if the skew angle is greater than 5 degrees. Large skews may require the use of two cross sections, one for the inlet and one for the outlet. Each drawing should show the lines representing the top of the pipe, the flowline of the pipe, bedding, foundation material, and the appropriate end treatment. The skew line is centered on a grid line that represents the centerline station of the pipe. The skew line is extended left and right of this point at the appropriate skew angle to a line perpendicular to the culvert end drawn on the cross section. Note the centerline station, skew angle, and inlet and outlet stations on the skew line. In addition, show the true angle of skew so that the pipe lengths can be determined from the skew line. Where skewed pipe cross sections are provided, placing the skew line on the cross sections is not necessary.

c. **Approach Pipes**. The cross section exhibits in the *MDT Sample Plans* illustrate the correct procedure for noting a sample approach pipe application.

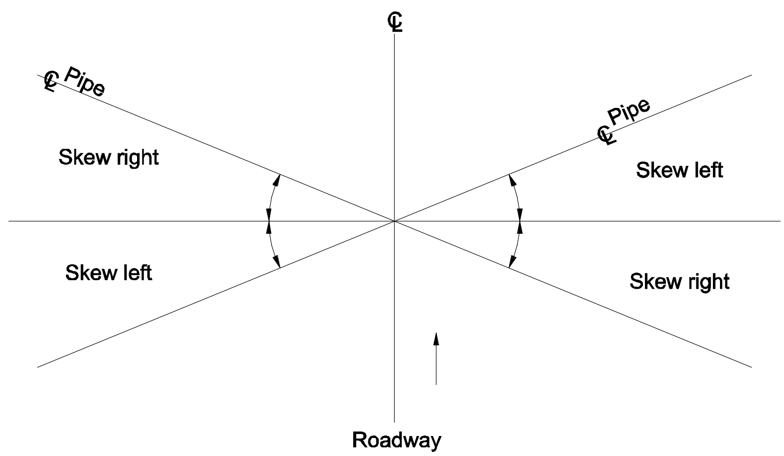
d. **Notes.** Culvert drawings should be supplemented with notes containing the following data, as appropriate:

i. Station location of culvert at the design centerline;

ii. Description of pipe, including material type (if no option), length, inside diameter, or span and rise;

iii. Amount of skew in degrees, measured right or left as shown in Exhibit 12-5;

Exhibit 12-5
Skew Measurements



iv. Description of end treatment;

v. Quantity of bedding material;

vi. Quantity of concrete;

vii. Quantity for edge protection;

viii. Quantity of foundation material and geotextile;

ix. Height of cover, measured from the top of the pipe to the top of the lowest point on the finished grade above the pipe; and/or

x. Pipe inlet/outlet invert elevations (as provided by the hydraulics designer).

2. **Ditch Blocks.** Indicate the elevation at the top of the ditch block (as provided by the hydraulics designer). Label ditch blocks at the closest adjacent cross section of the mainline and note them in the following manner:

26+10
DT. BLK. LT.
20 C.Y. EMB.+

3. **Drop Inlets, Curb Inlets, Manholes and Storm Drain.** Drop inlets, curb inlets, manholes and storm drains should be detailed on the cross sections.
4. **Drain Ditches.** Inlet and outlet drain ditches should be drawn on the cross sections and should be described by notation wherever they are used. Each note should indicate the station location, the cubic yards of additional excavation, whether it is an inlet ditch or an outlet ditch, and whether it is left or right of the mainline. A typical note is shown below:

   73+50
   OUTLET DT. LT.
   20 C.Y. ADD. EXC.

5. **Irrigation Facilities**. All irrigation facilities should be shown on the cross section by the design team. However, they will be designed and detailed by the Hydraulics Section. A typical note on the cross section for irrigation facilities is shown below:

   71+75
   NEW 24” x 126’ SIPHON
   SKEW 20° RT.
   1.6 C.Y. CONC. CL. GENERAL (INLET & OUTLET HEADWALLS)
   1.4’ COVER
   SEE DETAIL SHEET

6. **Structural Steel Plate Pipe Culverts (SSPP) Installations.** Structural steel plate pipe culverts will be shown on the cross sections. However, they will be designed and detailed by the Hydraulics Section. A typical note for large culverts is shown below:

   200+00
   NEW 60” x 120’ SSPP DRAIN, 0.138” THK.
   SKEW 30° LT
   2:1 STEP BEVELED END LT. AND RT
   5.9 C.Y. CONC. CL. GENERAL CUTOFF WALLS LT. AND RT.
   4.4 C.Y. CONC. CL. GENERAL EDGE PROTECTION - INLET
   30.6 C.Y. CLASS I CULVERT RIPRAP - OUTLET
   141 C.Y. GRANULAR BEDDING MATERIAL
   10.4’ COVER

12.3.13 Erosion Control Plan

The design team will supply a blank set of erosion control plans to the Contract Plans Bureau. The contractor will add the Best Management Practices (BMP) and submit them directly to the Department of Environmental Quality (DEQ).

12.4 THREE-DIMENSIONAL (3D) DESIGN

As MDT Construction project managers and contractors continually look for ways to reduce costs and improve profits, some contractors have begun using automated machine guidance. To use these evolving construction technologies, a digital design package is often required prior to construction. The design team should coordinate with MDT Construction for more information and guidance on producing 3D designs to support the project construction.

12.5 REFERENCES

1. Montana Department of Transportation (MDT). *MDT Survey Manual*. MDT, Helena, MT, 2005.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 13

Quantity Summaries

September 2016

Contents

Chapter 13

Quantity Summaries

In addition to preparing clear and concise construction plans, as described in Chapter 12, the design team needs to compile an accurate estimate of the project construction quantities. This information leads directly to the Engineer's Estimate, which combines the computed quantities of work and the estimated unit bid prices. An accurate estimate of quantities is critical to prospective contractors interested in submitting a bid on the project. Chapter 13 presents detailed information on estimating quantities for highway construction projects.

13.1 GENERAL INFORMATION

13.1.1 Guidelines for Preparing Quantity Summaries

The design team should consider the following guidelines when preparing quantity summaries:

1. **Specifications.** Cross-check all items against the *Standard Specifications*, the *Supplemental Specifications* and Special Provisions to ensure that the appropriate pay items, methods of measurement, and basis of payment are used. Items that are not addressed in the *Standard Specifications* or *Supplemental Specifications*, or items that are intended to be measured differently than identified in the specifications, need to have a Special Provision or Note included in the plans.
2. **Computations.** For the summaries, prepare a separate computation sheet for each item used on the project. Include all computation sheets in the project work file.
3. **Rounding.** The quantity of any item provided in the summaries should match exactly with the figure provided on the computation sheets. Note any required rounding of raw estimates on the computation sheets. Unless stated

otherwise, do not round the calculations until the value is incorporated into the summary frames.

4. **Quantity Splits.** Some projects will require quantity splits for work conducted under various financing arrangements. The quantities for District-wide pavement marking projects do not need to be split. Determine the need to separate project quantities into funding categories during the Preliminary Field Review.

   Two types of project splits are utilized: a hard split, which is a detailed separation of quantities, and a soft split, which splits the quantities using a ratio based on the major cost items on a project.

   Hard splits are required when the following circumstances occur:

   a. A portion of the project is inside a Reservation boundary
   b. Different funding sources are utilized
   c. The project has local government involvement/funding
   d. The project is located in more than one Financial District
   e. Special funding considerations (e.g., items that are fully funded by either state or federal funds on projects that are otherwise dual funded)

   For projects requiring hard splits, organize the summary frames to readily identify each division subtotal and the total of all divisions. Show subtotals in the summaries for all hard splits.

   Soft splits are utilized when the following circumstances occur:

   a. Portions of the project are in different counties
   b. The project is inside and outside of a urbanized boundary
   c. The functional classification of the route changes within the project limits

   Quantity subtotals are not required for soft splits and no changes to the plans are necessary. A ratio for the soft split will be provided to the Contract Plans Bureau on the plans submittal form.

   To determine the ratio for a soft split, calculate the cost of major items on a project. These typically include surfacing (plant mix and base), grading (including unclassified borrow), major structures (bridges, retaining walls), lump sum items, mobilization and traffic control. The ratio is then determined based on the cost in each portion of the project.

   Show all splits if more than one split applies to a project.

5. **Preliminary Cost Estimate.** Use the total values from the summary frames to develop the Preliminary Cost Estimate. All items described in the plans that are to be included in the cost estimate must be shown in the summaries. The Preliminary Cost Estimate is used for planning purposes in developing MDT's 5-year Tentative Construction Plan, and to help ensure that projects remain within budget. A link to the additional cost estimating tools provided on the MDT Website is shown in Section 13.2.

13.1.2 Quantity Estimates

For most projects, use computer software to develop the quantity estimates to the extent possible. The design team should manually verify automated calculations, as needed. For small projects, it may be more efficient to manually calculate quantities.

13.1.3 Units of Measurement and Rounding Criteria

Report quantity estimates in summary frames for all contract bid items consistent with the terms and units of measurement presented in the *Standard Specifications (1)*. Unless stated elsewhere in this chapter, round quantities consistent with the summary frames rounding criteria tables presented in Appendix J. Appendix J also provides a list of quantity conversions (e.g., rates/factors) to establish a consistent approach developing quantities for MDT bid items.

13.1.4 Item Codes

Contact the Contract Plans Bureau or the Contractors System link on the MDT website to obtain a copy of the official item list.

Each item used for measurement and payment in construction is identified by a 9-digit item number with a description. These numbers are used by the MDT's Construction Management System for tracking the project through construction. Note that the first three digits of the item number are coordinated with the *Standard Specifications (1)*. For example, Item #606010030 "Guardrail - Steel" is referenced to Section 606 "Guardrail, Median Barrier Rail and Guide Post" of the *Standard Specifications*.

The Contract Plans Bureau is responsible for numbering and naming the various items used in construction. Contact the Contract Plans Bureau or the Contractors System link on the MDT web site to obtain a copy of the official item list. Submit all proposed changes or additions to this list to the Contract Plans Bureau. The list of item codes is provided at the following link on the MDT website:

MDT Item Codes (English)

13.2 PROJECT COST ESTIMATES

Project estimates are used by Fiscal Programming and the Districts to develop the 5-year Tentative Construction Plan (TCP or Red Book) to ensure that sufficient funds are available for construction. The TCP is MDT's best estimate of when projects will be let and what the costs will be. The Engineering Division uses the TCP to prioritize project design. If cost estimates are too low, there will not be enough funding to fund all of the designated projects. As a consequence, resources will be focused on projects that can't be let to contract until the next fiscal year. If cost estimates are too high, the TCP will under-estimate the number of projects designated for the fiscal year.

During project development, several cost estimates are prepared to determine and refine the expected project construction costs. Project cost estimates are updated and included in all project milestone reports. MDT cost estimating tools and guidance is found at the following link on the MDT Website:

MDT Cost Estimating Information

The Engineer's Estimate is developed by using the final estimates from the various Sections and Bureaus involved with the project. The Contract Plans Bureau will be responsible for collecting and distributing the various units' final cost estimates to the Board of Review. The Board of Review includes representatives from the Construction Bureau, Road Design Section, Pavement Design Section and Contract Plans Bureau. The Board of Review will review and adjust the major bid item prices as deemed necessary. These items typically may include excavation, aggregate surfacing, plant mix surfacing, asphalt milling, erosion control, mobilization and miscellaneous work. The Contract Plans Bureau will review all other bid prices and prepare the Engineer's Estimate.

13.2.1 Estimating Procedures

When preparing a detailed cost estimate the design team should note the following:

1. **Funding Splits.** Some projects may have two or more funding sources. For example, where bridges comprise a substantial percentage of the total project, they may be funded separately under their own project coding. For these types of projects, separate cost estimates are required for each funding source based on the quantities within that particular funding source. The separation of quantities for funding splits will be determined during the project development.
2. **Quantities.** Show all estimated project quantities from the summary frames on the cost estimate. Some items may be shown as information purposes only. Do not include these items in the cost estimate. The totals from the appropriate summary frames are used in determining the cost estimate. Note that some summary frame totals are added to other frames (e.g., Additional Surfacing Frame totals are added to the Surfacing Frame). Therefore, the design team must be careful not to double count these quantities. Some items may have quantities shown in more than one frame. Combine these quantities when computing the cost estimate.
3. **Unit Prices.** For some items, particularly Traffic Control, Erosion Control, and other Lump Sum bid items, the estimating tools may not be appropriate for determining unit bid prices. Review of similar projects and input from the District Construction personnel should be used to aid in determining the unit prices.

13.3 EARTHWORK COMPUTATIONS

13.3.1 Computations

As stated in Section 13.1.2, most highway mainline earthwork computations are determined using the design software. Earthwork quantities for small projects, approaches, side roads, ditches and additional grading features may need to be calculated manually. For either method, earthwork volumes are calculated using an average end-area method. The following are items typically needed for calculations:

1. horizontal and vertical roadway alignments;
2. typical sections;
3. terrain data;
4. shrink and swell factors (unclassified excavation projects);
5. cut and fill slope rates; and
6. identification of sections not to be included (e.g., bridge sections).

End-areas for each cross section of the mainline are used for mainline quantities. Examples of manual computations for end-area calculations are provided in Appendix K.

13.3.2 Shrink and Swell Factors

For projects using unclassified excavation as the grading bid items, adjust excavation and/or embankment quantities, calculated either manually or by the computer, by the appropriate shrink and/or swell factor(s). The use of more than one factor for a project is often necessary to describe the characteristics of the excavated material. However, do not apply both shrink and swell factors to the same material. The factors used in the calculations will depend on the soil type, quantity to be moved and historical data. The applicable shrink factors to be used in the calculations are provided by the District construction personnel, based on historic values for the project location and scope. Swell factors, when necessary, are determined by geotechnical review of the soil survey information. Typically, shrink factors range from 20 to 30 percent when adjusting embankments, and 20 percent is often the assumed value used for preliminary design in the absence of historical data. Swell factors generally range from 5 to 15 percent when applied to excavation of rock.

The unadjusted excavation quantities are still measured for payment.

For most MDT projects, the shrink factor is applied to proposed embankments, as this simplifies the calculation for unclassified borrow and more closely represents the amount of haul proposed. For projects with multiple shrink and swell factors, it is easier to track material volumes by making adjustments to the excavated materials. However, the unadjusted excavation quantities are still measured for payment.

13.3.3 Balancing

For most large projects, it is desirable to provide an earthwork balance for the project (i.e., excavation equals adjusted embankment quantities). However, due to the degree of accuracy of shrink/swell factors and the nature of grading work, do not make an extensive effort to produce an exact zero earthwork balance. Typically, a project is considered balanced if the borrow/excess quantity is within 3 percent of the total excavation quantity. If the earthwork is balanced within 3 percent, show the borrow or excess quantity with an asterisk (*) and a note stating “For informational purposes only” if excess, or a note stating “Include the cost of the borrow quantity in the cost of other grading items” if borrow is required. A small amount of excess is preferred over a small amount of borrow on a project, because in most cases, a disposal site for a small excess quantity can be easily found. A small amount of borrow will likely be bid at an inflated price, if measured for payment. Unbalanced projects will require the contractor to haul extra material (e.g., borrow) or remove excess material (e.g., excavation) from the project, which will typically increase construction costs. Balancing within the project limits can be accomplished by revising the profile grade line, cut and fill slopes, ditch profiles, and by daylighting sections.

To determine if balancing is appropriate for a project, consider the following guidelines:

1. **New Construction/Reconstruction Projects**. For new construction, make every reasonable effort to balance the project. For reconstruction projects, balancing the project is desirable; however, its importance is secondary to the project purpose and need. Modernizing a facility generally results in greater width, improved sight distances, and flatter slopes which all contribute to the amount and location of grading required. Balancing earthwork should not be accomplished at the expense of the improved roadway geometrics. For some locations, balancing earthwork will not be cost effective or desirable, due to poor or saturated subgrade materials or physical constraints. It is often desirable to build over existing side borrow roadways to avoid the need for subexcavation and special borrow.
2. **Rehabilitation Projects.** Grading on rehabilitation projects is generally dictated by the project scope, with little room for adjustment. Determine the need for balancing the project on a project-by-project basis.
3. **Other Projects**. For urban projects, interchange projects and pavement preservation projects, it is generally impractical to provide a balanced grading design. Therefore, it will not be necessary to balance earthwork quantities on these project types.

It is generally not cost effective to balance a project over long distances. On long projects, provide several intermediate balance points. Preferably, the distance between balance points should not exceed 2 miles. Hauling material across bridges to achieve a balance is undesirable.

13.3.4 Mass Diagram

On projects where the grading is bid as unclassified excavation, prepare a mass diagram to illustrate how the grading will be accomplished. Do not include the mass diagram in the final plans package submitted to the Contract Plans Bureau.

To better understand the application of a mass diagram, consider the following guidelines:

1. **Curve.** The mass diagram curve illustrates a cumulative, algebraic summation of the adjusted excavation and embankment quantities, typically from the start of the project. A rising curve in the direction of summation indicates excavation exceeds embankment, and a falling curve indicates embankment exceeds excavation. Inflection points (e.g., curve crests and sags) represent points where the net earthwork changes from a

cut to a fill or vice versa. The horizontal distance on the mass diagram represents the horizontal distance on the ground in stations. The vertical distance represents the net accumulation of earthwork volume in cubic yards.

2. **Balance Line.** A balance line is any horizontal line which intersects the mass summary curve in at least two places. This indicates that the excavation and embankment quantities are balanced between the two intersecting points. These intersection points are called balance points. For most projects, the balance line is typically started at zero at the beginning of the project.
3. **Balance Points.** Once the grades have been finalized and the earthwork has been balanced, compute the balance points and the earthwork quantities for summarization. It is not always necessary to compute earthwork quantities for each balance point. Several small balance points may be combined if they are within distances of approximately 1,000 feet. Example computations are provided in Appendix K.
4. **Borrow/Excess.** If the grading curve does not end on the balance line, draw a vertical line from the curve to the balance line. Note the amount of borrow or excess next to the vertical line. The location of the borrow pit or waste disposal location will typically be determined by the contractor. As stated in Section 13.3.3, long distances between balance points or over bridges are generally not cost effective. To force balance a section, the balance line may need to be adjusted up or down within the limits of a project. Downward adjustments in the balance line indicate the need for borrow at the point of force balancing, and upward adjustments indicate excess material.
5. **Quantities**. Show the adjusted amounts of excavation and embankment on the mass diagram between each set of balance points.

13.3.5 Unclassified Excavation

The following presents the procedures for recording unclassified excavation quantities on the Grading and Additional Grading Frames:

1. **Roadway Quantities.** Typically, all the roadway grading quantities are shown on one line of the Grading Frame. If forced balancing within a project is required, represent each side of the forced balance point on a separate line. Include columns for each of the following as appropriate, based on how the earthwork was estimated:
   a. **Unclassified Excavation.** Always include the unadjusted volume of excavation, as this is measured for payment for all cases.
   b. **Adjusted Excavation.** Only shown when excavation is adjusted due to rock on the project. Indicate as “FOR INFORMATION ONLY”.
   c. **Emb.+.** This is the amount of adjusted embankment based on the project shrink factor, and is typical for most unclassified excavation projects. Indicate as “FOR INFORMATION ONLY”.
   d. **Unadjusted Embankment.** This represents the actual volume of embankment, and is only used when all excavation is adjusted for a project with rock excavation. Indicate as “FOR INFORMATION ONLY”.

e. **Excess Excavation/Unclassified Borrow.** Typically a project will result in either excess material or the need for borrow. This quantity is only shown in the Grading Frame total row based on all project volumes. Excess Excavation is shown "FOR INFORMATION ONLY". Unclassified Borrow is measured for payment unless it is 3 percent or less of the total Unclassified Excavation quantity.

2. **Additional Grading**. Additional grading is the excavation and embankment required for constructing the items of work in addition to the mainline roadway template required for the project. The Additional Grading Frame will include all the same columns used in the Grading Frame, except for Excess Excavation/Unclassified Borrow and may include an additional column labeled "ADD. UNCL. EXC." Embankment quantities should always be included in the roadway quantities. Excavation quantities fall into two categories as follows:

   a. **Suitable Material.** If the material is suitable, include the quantity in the mainline roadway quantities. Material is considered suitable if it consists of an acceptable soil type and the quantity is large enough to make handling practical. Examples include approaches, widening, and slope flattening.

   b. **Unsuitable Material.** If the material is unsuitable, designate the quantity as an "ADD. UNCL. EXC." item but do not include this item in the mainline roadway quantities. Material is considered unsuitable if:

      - It contains soil or organic matter unsuitable for foundation material, regardless of moisture content; or
      - It is too wet to be properly compacted and cannot be dried within a demonstrated reasonable time frame prior to incorporating into work. Excessive moisture alone is not sufficient cause for determining unsuitable material.

      Examples include material near inlet and outlet ditches, and existing ditches graded to drain.

   Do not use the additional excavation item ("ADD. UNCL. EXC.") as a catch-all for late entries. Items with significant volumes that are added late in the design phase require inclusion in both the mainline roadway quantities and the mass diagram to reflect the changes such quantities have on balances and volumes.

3. **Topsoil Replacement**. Topsoil replacement is the volume of embankment required to fill the void left after the topsoil has been removed. This quantity mathematically re-establishes the ground line to its original state prior to topsoil removal. Adjust topsoil replacement quantities by employing the same shrink factor used for mainline grading quantities in the area that the topsoil was removed. Include topsoil replacement in the roadway quantities for all projects. This results in representing topsoil replacement as an embankment or borrow quantity. Show the project total for topsoil replacement as an "EMB+" quantity in the "INCL. IN ROADWAY" column of the Additional Grading Frame. Although this quantity is shown once in

the summary frame, it should be split out every 30 stations for inclusion in the earthwork run and mass diagram to better represent its effect on earthwork balances.

4. **Subexcavation.** On reconstruction projects, subexcavation is generally a specified depth of excavation of unstable material below subgrade in existing fill or natural ground. Always specify subexcavation depth from the top of the subgrade elevation unless an unusual circumstance justifies another reference. Typically, this material can be excavated using the equipment and procedures normally used for unclassified excavation. If the material is unsuitable for embankment material, the subexcavation also includes the disposal of the material. Material is considered unstable if it contains saturated soils, mixtures of soils, and/or organic matter that is unsuitable for embankment material. Examples of unstable material include swelling clays or silty soils having low support value or subject to frost heaving.

   An unclassified excavation quantity is used to remove subexcavated material and either place it in embankments or dispose of it. If the material may be used for embankments, include the quantities in the earthwork run and denote the quantities shown in the Subexcavation Frame with an asterisk ("*") and a note stating "INCLUDED IN ROADWAY QUANTITIES." Record these same quantities in the "INCL. IN ROADWAY — UNCL. EXC." column of the Additional Grading Frame. If the material is to be disposed, record the quantity in the "UNCL. EXC." column of the Subexcavation Frame only. This quantity should not be included in the Additional Grading Frame or the earthwork run.

5. **Subexcavation Replacement.** If subexcavation is not replaced with special material, include the adjusted quantities in the earthwork run and show these quantities in the "INCL. IN ROADWAY – EMB+" column of the Additional Grading Frame. If special borrow is provided, show the actual quantity of special borrow in the Subexcavation Frame. The *MDT Sample Plans* provide additional information.

6. **Unclassified Borrow.** Unclassified borrow for embankment construction is contractor-furnished material excavated from outside the right-of-way or construction easement areas. Sources for this material must be approved by MDT and meet current environmental and cultural resource preservation regulations. Show the amount of unclassified borrow in the Grading Frame and mass diagram. It should be noted that the unclassified borrow is assumed to have the same shrink/swell factor and structural value as the unclassified excavation on the project.

13.3.6 Embankment-in-Place Projects

Use the embankment-in-place item on projects with embankment quantities less than 25,000 cubic yards where embankment exceeds the excavation quantity. In addition, embankment-in-place may be used when the embankment quantity exceeds the excavation quantity and the embankment quantity is between 25,000 and 75,000 cubic yards.

The use of embankment-in-place will be made on a case-by-case basis and should be discussed at the Alignment and Grade Review stage. Some of the following factors should be considered in the decision to use embankment-in-place.

- The embankment greatly exceeds the excavation.
- The use of embankment-in-place is putting too much risk on the contractor – recognizing that embankment-in-place typically costs two to three times more per cubic yard than unclassified excavation.
- The project includes other types of materials such as special borrow in the top 2 feet of the subgrade that would require different methods of measurement, possibly from the same source.
- The mass diagram provides useful information regarding the movement of earthwork.

The use of embankment-in-place should not replace good design practices and the evaluation of in-situ soils and other grading considerations.

The following presents the procedures for recording the embankment-in-place quantities in the Grading and Additional Grading Frames:

1. **Shrink/Swell Factors**. Do not adjust the excavation or embankment quantities with shrink or swell factors.
2. **Additional Grading Frame**. Show both the embankment and excavation of suitable material quantities in the Additional Grading Frame. Suitable material is defined in Section 13.3.5, Item 2. Add the totals from the Additional Grading Frame to the Grading Frame.
3. **Minor Excavation.** Additional grading items consisting of small excavation quantities and/or excavation of unsuitable material will be paid as embankment-in-place. Unsuitable material is defined in Section 13.3.5, Item 2. Show these excavation quantities in the "ADD. EMB. IN PLACE" column of the Additional Grading Frame and total. This quantity is not used to determine the amount of borrow required for the project.
4. **Topsoil Replacement**. Show the project total for topsoil replacement as an "EMB. IN PLACE" quantity in the Grading Frame. However, it should not be adjusted for shrinkage.
5. **Subexcavation.** An embankment-in-place quantity reflects the removal of subexcavated material that is either placed in embankments or disposed of. Show the quantity as a line item in the Grading Frame. Denote the total of the Subexcavation Frame with an asterisk ("*") and a note stating "Included in the Grading Frame."
6. **Subexcavation Replacement.** If subexcavation is not replaced with special material, no subexcavation replacement quantity is needed, as the subexcavation is already measured as embankment-in-place. If a special material is required, show the actual quantity as a special borrow item in the Subexcavation Frame.
7. **Mass Diagram.** A mass diagram is not required for embankment-in-place projects.

13.3.7 Miscellaneous Considerations

In addition to the above, the following information provides additional considerations when determining earthwork quantities. Section 13.6.9 also provides considerations for grading with rock.

1. **Street Excavation.** Street excavation is typically used on urban projects and consists of the excavation of all material within the specified template. Street excavation should be utilized when the design team anticipates that material is present that is not normally encountered in typical unclassified excavation (e.g., abandoned pipe, old foundations, curbs and sidewalks). Street excavation is typically used instead of, not with, unclassified excavation. When both are used on a project, the location where each is measured must be specifically defined.
2. **Digout Excavation.** Digout excavation is used for removal of the existing roadway and unstable subgrade materials for projects that do not have other grading items. The District Office and the Geotechnical Section are responsible for determining the need for and location of digouts. The design team is responsible for incorporating their recommendations onto the plans. The excavation and disposal of existing surfacing and subgrade is measured and paid for by the cubic yard of "Digout Excavation." Special material is required for the subgrade portion of the digout replacement, and is measured and paid for as special borrow or as special backfill as determined by the Geotechnical Section and shown in the Digout Frame. Where digouts are required, include a detail showing all removal and replacement thicknesses in the plans.
3. **Muck Excavation.** Muck excavation is removing and disposing of unsuitable material in cut sections or below the natural ground line in embankment sections. Material defined as muck must be deemed unsuitable, as defined above, and is unable to be excavated using the same equipment and methods as for unclassified excavation. Muck excavation and muck excavation replacement material is called out in a similar fashion to subexcavation of unsuitable material, but in the Muck Excavation summary frame. Muck excavation is only used on projects with another grading bid item (e.g., unclassified excavation, street excavation, or embankment-in-place). For projects without grading, use digout excavation.
4. **Unclassified Channel Excavation.** Unclassified channel excavation is the excavation and disposal of all material for either the construction of new water courses and channels or the modification (e.g., widening, deepening, straightening) of existing channels. Unclassified channel excavation is typically specified when the excavated material is not used to construct roadway embankments.
5. **Special Borrow.** Special borrow for embankment construction is material that has a specific minimum R-value or soils-class designation. Typically, special borrow is contractor-furnished material excavated from a Department-approved source outside the right-of-way or construction easement areas. Use the following guidelines where special borrow is required:

R-value, also known as the resistance value, is the ability of the soil to resist lateral spreading due to an applied vertical load.

a. **Reducing Surfacing Section Thickness.** To reduce a surfacing section's depth and cost, its design may be based on a minimum R-value, for the top 2 feet of subgrade that is higher than that of readily available material. This practice frequently requires the use of special borrow. In this case, for the top 2 feet of subgrade, calculate the quantity of special borrow required from a MDT-approved source rather than relying on a special provision to specify the material's minimum R-value or soils-class designation. The use of a special provision, in this case, generally results in a cost increase and requires the contractor to selectively grade the project to meet the requirements. Without specific guidance, the contractor will estimate the quantity and source of the special borrow material, and any uncertainties will tend to produce overly conservative estimates and higher bid prices from the contractor. If special borrow is recommended to reduce the surfacing section thickness, the special borrow may be treated as either part of the surfacing section or included in the subgrade. Refer to Section 12.3.6 for guidance as to how the special borrow should be shown. Where special borrow that is used to reduce the surfacing section is included in the subgrade, it should not be shown in the profile view. For both methods of special borrow placement, ensure that the mass diagram and the grading quantities reflect roadway construction to the bottom of the special borrow.

b. **Unsuitable Material Replacement.** If special borrow is recommended to replace unsuitable material, do not consider it as part of the surfacing section. The subexcavation limits, depth and replacement material (i.e., special borrow) will be shown in a detail. The location and depth of special borrow will be designated by cross-hatched areas on the profile and cross sections. The roadway template shown on the cross sections will be at the bottom of the surfacing section. Ensure that the mass diagram and the grading quantities reflect roadway construction to the bottom of the surfacing section; however, do not include special borrow for subexcavation in the grading quantities or mass diagram. In addition, do not include subexcavation material in the grading quantities or mass diagram if disposed outside the roadway template.

Where special borrow is specified, verify the material's availability and cost effectiveness. The required material may not be available in close proximity to the project or may be too costly or difficult to obtain from landowners. If an excessive price for special borrow is anticipated, it may be cost effective to redesign the roadway typical section. Discuss these issues during the Alignment and Grade Review meetings with District Construction, Materials, and Right-of-Way personnel. The design team should also discuss with District Construction how special borrow will be measured. Special borrow is typically measured in place and no shrink factor is applied. However, District personnel may elect to measure special borrow at the source (borrow site). A shrinkage factor needs to be applied to the material when it will be measured at the pit, and it is represented as Excavation Special Borrow in the plans, special provisions and estimate.

6. **Approach Grading.** The approach grading will be paid the same as the mainline grading. Approach fills will utilize 6:1 slopes within the clear zone, regardless of fill height. This does not apply where the approach is shielded with guardrail. See the *MDT Detailed Drawings* for cut and fill slopes beyond the clear zone. The fill slopes on public approaches will at least match the existing slopes.

   More detailed earthwork calculations may be necessary for approaches involving a significant realignment (e.g., button hook approaches) or change in grade. Details that include a plan and profile should be provided for public approaches. For private or farm field approaches, show the horizontal alignment with the appropriate curve radii on the plan sheet. Also provide a profile of the approach on a detail sheet.
7. **Widening Behind Guardrail**. Additional embankment material and/or surfacing material is required for slope flattening behind guardrail. See the *MDT Detailed Drawings* for configuration of slope flattening. Use aggregate surfacing material for material placed above subgrade. Depending on the quantity involved, use either embankment or aggregate material for material placed below the subgrade. For projects without grading, widening behind guardrail end sections may be measured as each, without calculated volumes. This should only be used when the work can be accomplished within the existing right-of-way.

13.4 DRAINAGE COMPUTATIONS

Chapter 11 presents principles and criteria for the design and consideration of pipes, culverts, culvert ends, bedding material, riprap, irrigation facilities, storm drains and other drainage items. The design team should note the following for measuring and determining quantities of drainage items:

1. **Pipe Sizes**. Mainline culverts will be 24”diameter or greater. Approach pipes are typically 18” in diameter unless a hydraulic analysis indicates a larger size is needed. The culvert size indicated in the plans should match the bid item description.
2. **Optional Pipe.** On projects where optional material for mainline culverts is appropriate, specify all options for each culvert installation, as recommended by the Hydraulic Section. Indicate the size and thickness or class of each optional pipe option indicated, including the type of coating required. Irrigation or siphon should be noted, if applicable. Specify the standard corrugation sizes for steel and aluminum pipes and note any exceptions. For each option, compute and report separate quantities for bedding, foundation material, concrete, and geotextile material. Information on culvert size and any special requirements for thickness, class and/or corrugation size will be furnished by the Hydraulics Section for any culvert larger than 24 inches on the mainline and 18 inches on the approaches. Plastic options may be included for approach pipes. List the approach pipes in a separate summary.

3. **Alternate Culvert Material Bids.** All culverts that are greater than 10 feet in diameter, and where steel and concrete are considered appropriate materials, must be bid as alternates. Provide an alternate culvert frame for each material.
4. **End Sections**. List the appropriate end section only if a new one is required. If the end section is removed and relayed, leave the "End Section" column in the Culvert Summary blank. Include the length of the end section in both the remove culvert and relay culvert columns, and note the end section is to be relayed in the remarks column.
5. **Basic Bid.** When steel is an option, the basic bid culvert is always steel pipe. Therefore, the size, quantity, length, etc., for the culvert is the same as that for steel pipe, even though these characteristics may differ for pipe options (e.g., concrete pipe). If steel pipe is not an option, the basic bid item for culvert is the quantity of concrete pipe. If only one type of culvert is specified, the basic bid item is the quantity of that particular pipe.
6. **Culvert Recap Frame.** Summarize the basic bid items of the Culvert Summary Frame in the Culvert Recap Frame and present the total length of each pipe size and the total quantities for bedding material, concrete, foundation material, relay pipe, geotextile, remove pipe and riprap. List irrigation pipe and siphons separately from drainage pipe in the recap. Reference the pipe material, if only one culvert option is specified. The Culvert Recap Frame is only used when optional pipe material is used.
7. **Non-Optional Pipe**. On projects where optional culvert material is inappropriate (e.g., the type of material is specified), the Culvert Frame (No Option) should be used. Use this frame only if pipe options are not given on the project (e.g., an overlay and widening project where existing culverts are only being lengthened). If both optional and non-optional pipes exist in the project, use the Optional Culvert Frame.
8. **Storm Drains.** Storm drain designs will be prepared by the Hydraulics Section including trench and bedding details. Use the Storm Drain Frame to record quantities for storm drain culverts and appurtenant items. For most projects, the option bid provision will not apply to storm drain installations. Where options are proposed, the Hydraulics Section will provide the recommendations for storm drain installation. Include this information in the summaries and indicate the optional sizes and material types. Where optional materials are specified, the basic bid item is concrete. The design team will be responsible for calculating the quantity of trunk line, lateral lines, trench excavation, bedding, and length of removed storm drain. Record all quantities for the storm drain facility in the appropriate frames. Storm drain pipe bid lengths are measured from center to center of manholes and drop inlets. Trench excavation is calculated using the "bid" length of pipe. Bedding is calculated using the actual pipe length (length of pipe from inside wall to inside wall of manholes and drop inlets).
9. **Water Mains.** List water mains in a separate frame from storm drains because they are normally funded separately and include items not applicable to storm drains.

10. **Existing Culverts.** List the size, length and type of pipe for all culverts to be removed. Culvert removal will be paid by the linear foot of pipe removed regardless of pipe size. Relaying of culverts is measured and paid per length of culvert to be relayed regardless of pipe size. Lengthening existing culverts is measured and paid per length and size of new pipe. See Chapter 11 for criteria on culverts and extensions.

    Existing pipes that are plugged and abandoned will be paid per each. Existing pipes that are filled and abandoned will be paid based on the volume of material required to fill the existing pipes. The volume will be determined based on the nominal diameter and effective length of the pipe.

11. **Trench Excavation.** Trench excavation is not measured for payment. The quantity of trench excavation is shown for informational purposes. Trench excavation is typically specified where vertical trench walls are necessary and the trench width is provided (e.g., storm drain). Calculate the quantity of trench excavation by the volume bounded by the bottom and length of the pipe and by vertical planes 1.5 feet outside the pipes inside wall or to the width and depth of the bedding/foundation material, whichever is greater. The cost of trench excavation is included in the unit price bid per linear foot of new storm drain, and associated bedding/foundation material.

12. **Riprap.** The Hydraulics Section will specify both the use and dimensions of riprap for permanent erosion control in conjunction with pipe installations. Where excavation is required for riprap placement, the cost of excavation is included in the unit price bid for riprap. For riprap installations at bridges, the type, quantities, and design data are determined through coordination with the Hydraulics Section and the Bridge Bureau.

13. **Clean Culverts.** The Federal Highway Administration (FHWA) has determined that there will be no federal participation for cleaning culverts less than or equal to 48". Federal participation for culverts greater than (>) 48" will be determined on a case-by-case basis. This also applies to off-system projects, even though MDT is not responsible for maintenance.

    Consequently, do not include culvert cleaning on projects unless FHWA has determined that participation is appropriate or unless MDT has agreed to use state funds for culvert cleaning.

14. **Pipe Length.** Draw cross drains to scale at the proper flowline on the nearest template cross section. See Chapter 11 and the *MDT Detailed Drawings* for end section criteria and dimensions. If the installation is perpendicular or skewed less than 5 degrees, then the pipe length may be scaled directly from the cross sections. Also consider the following:

    a. Do not bid FETS (Flared End Terminal Section) and RACETS (Road Approach Culvert End Treatment Section) separately. Include them in the length of pipe.

    b. Where beveled ends are used, measure the pipe length along the pipe flowline.

    If the pipe is skewed more than 5 degrees, scale its length along the skewed line.

No additional pipe length is required where skewed beveled end sections are provided on a skewed pipe. However, if end sections are perpendicular to the centerline of the skewed pipe, additional pipe length is required.

15. **End Treatments**. Quantities for cutoff walls, concrete edge protection and riprap for each pipe size are presented in the *MDT Detailed Drawings*. Adjust end treatment quantities for skewed beveled end sections as follows:

Equation 13.4-1

$$T = \frac{Q}{\cos\theta}$$

Where:

T = adjusted quantity, cubic yard
Q = quantity from the *MDT Detailed Drawings*
θ = angle of skew, degrees

16. **Bedding and Foundation Material**. For culverts less than or equal to 48 inches in diameter, bedding is paid for with the cost of the culvert and does not need to be shown in the Culvert Summary. For culverts greater than 48 inches in diameter, bedding must be quantified and paid for separately and specified in the Culvert Summary in accordance with the *MDT Detailed Drawings*. Where foundation material is specified, it is quantified and measured for payment in all cases.

17. **Stockpasses and Vehicular Underpasses.** Stockpass and vehicular underpass lengths are measured along the invert of the structure. The quantities for vehicular underpasses should be recorded in a separate summary frame.

13.5 ROADWAY COMPUTATIONS

The Pavement Analysis Section is responsible for determining the type of finished surface, pavement material type and various course thicknesses. The design team is responsible for recording this information on the construction plans and calculating the roadway quantities. Use the criteria and procedures presented in this Section to prepare the typical sections and quantities. The basis for roadway quantities is presented on the Notes Sheet.

13.5.1 Typical Section Geometrics

The following sections present recommended procedures for determining the horizontal dimensions of various surface courses. These horizontal dimensions are used for developing the surfacing quantities and for field construction staking. Surfacing thicknesses are typically identified on the typical sections in 0.05-foot increments; however, depths may be specified to 0.01-foot increments for some applications The precision is used to identify thicknesses of existing materials is also 0.01–foot, when applicable.

13.5.1.1 Symmetrical Sections

The most commonly used typical section is the two-lane highway on a tangent alignment with normal cross slopes. In this typical section, the dimensions of the subgrade width and intermediate surfacing courses are symmetrical about the centerline. The finished roadway width will be determined according to the criteria in the *MDT Geometric Design Standards* or as determined during the Preliminary Field Review *(2)*. Example calculations are provided in Appendix K.

13.5.1.2 Unsymmetrical Sections

Where sections are not symmetrical about the centerline, compute and record the widths to the left and right of centerline separately. Unsymmetrical sections exist with each superelevated section and with divided highways where inside and outside shoulders have different widths. The widths of unsymmetrical section are determined through the following and example calculations are provided in Appendix K:

a. Superelevated sections
b. Divided highways
c. Intermediate (high side)
d. Intermediate (low side)

13.5.2 Typical Section Quantities

In most cases, the quantities required to build the tangent sections are used to approximate the total quantities for the project. Where superelevated typical sections account for the majority of the project length, or when a superelevated section does not have a tangent typical of the same top width, provide typical quantities for those sections as well. For each typical section where quantities are shown, determine the quantities per station for each type of surfacing material. These quantities will be used to compute the total mainline surfacing quantities for the project. Use the procedures indicated below and in Appendix K, along with the basis of plan quantities to calculate typical section quantities. The descriptions and examples provided in this manual cover the most commonly used surfacing materials. For instances when new or less common materials are used, or items are measured differently than indicated (e.g., tons instead of gallons), the design team should use the process that most closely matches the material application and method of measurement to determine and show typical quantities.

Exhibits 13-1 and 13-2 provide quantities frame rounding criteria for typical sections.

Exhibit 13-1 Quantities Frame Rounding Criteria (Typical Sections)

Quantities								
	Aggregate				Bituminous Material			
Units	Cover	Plant Mix	Crushed Agg. Course**	Units	Asphalt Cement	Seal	Tack	Agg. Treatment
Area ft²	—	0.01	0.01	yd^3/Sta.	—	1	1	1
yd^3/Sta.	—	0.1	0.1	ton/Sta.	0.01	0.01	—	—
ton/Sta.	—	0.1	*0.1	Gal/Sta.	—	—	1	—
yd^2/Sta.	1	—	—	—	—	—	—	—

*The basis of payment for these items is typically paid for at the unit price bid per cubic yard.
** Crushed Base Course or Crushed Top Surfacing may be specified for gravel roads.

Exhibit 13-2 Quantities Frame Rounding Criteria Cement Treated Base (Typical Sections)

Quantities													
Aggregate							Bituminous Material				Cement		
Units	Cover	Plant Mix	Cr. Agg. Course	Cement Treated Base	Blotter	Units	Asphalt Cement	Seal	Tack	Curing Seal	Portland Cement **	Fly Ash **	Agg. Treat.
Area (ft²)	—	0.01	0.01	0.01	—	yd^2/Sta.	—	1	1	1	—	—	1
yd³/Sta.	—	0.1	0.1	0.1		ton/Sta.	0.01	0.01	—	0.01	0.01	0.01	—
ton/Sta.	—	0.1	0.1*	0.1	—	Gal/Sta.	—	—	1	—	—	—	—
yd^2/Sta.	1	—	—	—	1	—	—	—	—	—		—	—

*The basis of payment for these items is typically paid for at the unit price bid per cubic yard.
** Portland Cement and Fly Ash may not be measured separately depending on application or current MDT practice. Show only if measured for payment.

13.5.2.1 Aggregate Quantities

The left side of the Typical Section Quantities Frame is used to show the quantities per station for all aggregate type materials included in the project surfacing section. Example calculations are provided in Appendix K.

1. **Aggregate Cover Material.** For projects with Seal and Cover, calculate the square yards per station and record this value in the "COVER" column of the Typical Section Quantities Frame.
2. **Plant Mix Quantities.** The total aggregate quantity of the Plant Mix Surfacing is shown in the Typical Section Quantities Frame. Include the cross sectional area, cubic yards per station, and tons per station for each type of Plant Mix Surfacing specified.
3. **Leveling & Isolation Lifts.** Leveling quantities should not exceed 25 percent of the mainline quantity for a planned overlay. If more than 25 percent is required, the project is probably not a good candidate for a single-lift overlay.

   When a plant mix overlay is placed on a surface that has been crack sealed, the heat from the plant mix overlay causes the sealant to expand resulting in a bump in the riding surface. MDT has determined that placing an extremely thin lift of plant mix prior to placing the primary overlay will reduce the effects of the sealant expansion on the riding surface. This application is called an isolation lift.

   The decision to use an isolation lift will be made at the Preliminary Field Review. The use of isolation lifts generally applies to pavement preservation projects, although they could be used on designed overlay projects with plant mix thicknesses less than 0.30 feet. Isolation lifts are not needed on projects that include milling of the travel lanes. MDT recommends that milling be considered as an option for treating surfaces that have extensive crack sealing.

   To ensure that adequate surfacing is provided in the plans, a minimum 0.22 feet overlay thickness will be required whenever an isolation lift is needed. The isolation lift is placed with a paver or other approved method to a minimum thickness of 0.07 feet. Leveling used to correct distortion in the road's surface may be placed in conjunction with the isolation lift, but this will depend on the project specific characteristics of the road surface.

   The quantity for the isolation lift is included in the overall lift thickness (e.g., a 0.22-foot overlay will be shown in the typical section even though the 0.07 feet isolation layer will be placed in a separate operation than the 0.15-foot overlay). Leveling used to correct distortion in the road's surface will continue to be shown as a separate quantity in the Additional Surfacing summary and not called out on the Typical Section Quantities Frame.
4. **Crushed Aggregate Quantities.** When crushed aggregate surfacing is included on the typical section, the cross sectional area and cubic yards per station are shown in the Typical Section Quantities Frame. If the crushed aggregate is to be measured by the ton, also include the tons per station. Include a separate column for each different type of crushed aggregate

material specified (e.g., Crushed Aggregate Course and Crushed Top Surfacing).

5. **Cement-Treated Surfacing**. Use the following guidelines to estimate cement-treated surfacing quantities:
   - **Cement-Treated Base (CTB).** Cement is added to the CTB to increase the structural strength of the surfacing. The greater strength allows the use of thinner aggregate sections. The minimum thickness for CTB is 0.65 feet. CTB typically extends 1.0 feet beyond the outside edges of the travel lanes and then downward on a 1:1 slope to the top of the subgrade. Crushed Aggregate Course of equal depth is used for the remaining gravel section. Calculate and show the cross sectional area and cubic yards per station of the CTB shown on the Typical Section. For cases where the cement is measured separately, that quantity is based on a percentage of the overall weight and therefore, the tons per station for the CTB must also be shown for information only.
   - **Cement-Treated Pulverized Base.** A cement-treated pulverized base also increases the strength of the surfacing. The existing paved surface is pulverized and mixed with the existing base aggregate prior to application of the cement. The cement is then added and mixed through a second pulverization. Calculate the square yards of Cement-Treated Pulverized Base and record the total in the "CEMENT TREATED PULVERIZED BASE" column of the Typical Section Quantities Frame. The depth of pulverization and the percentage of cement will be provided by the Materials Bureau. Record the computed quantity in the "CEMENT" column of the Typical Section Quantities Frame using the information provided in Exhibits 13-1 and 13-2.

     The Surfacing Design Section will determine the need for cement-treated and cement-stabilized bases. However, a CTB alternate may be considered when the depth of the crushed aggregate course exceeds 1.30 feet, a thinner surfacing section is desired to reduce impacts, or when gravel sources are an issue.
6. **Blotter.** On projects with cement-treated base, use blotter material to cover the curing seal. Calculate the area of the Cement-Treated Base (CTB) surface in square yards per station.

13.5.2.2 Bituminous Material Quantities

The right side of the Typical Section Quantities Frame is used to show the quantities per station for all non-aggregate materials that are measured for payment in the project surfacing section. Example calculations are provided in Appendix K:

1. **Performance Graded Asphalt Cement**. All grades of asphalt cement will be referred to as Performance Graded Asphalt Binders (PGAB). The PGAB will be followed by two numbers (e.g., PG 64-28). The first number is an indicator

of rut resistance and the second number is an indicator of its resistance to thermal cracking at temperature extremes.

Separate columns should be provided where more than one PGAB is used on a project.

Asphalt contents (by percent weight) vary from region to region, and statewide averages may not accurately predict the asphalt content on some projects. Specifying project-specific asphalt contents will increase the accuracy of project cost estimates and reduce the possibility of unbalanced construction bids. Project-specific asphalt contents should be used on projects where Grade S volumetric PMS is specified.

The tons per station of asphalt cement quantity is calculated by multiplying the project specific asphalt content by the tons per station of plant mix. Record this value in the bituminous material "ASPHALT CEMENT" column of the Typical Section Quantities Frame using the rounding criteria illustrated in Exhibits 13-1 and 13-2. When the asphalt cement is included in the cost of Plant Mix Surfacing (e.g., Commercial Plant Mix bid items), do not show a value in the Typical Section Quantities Frame.

2. **Seal Oil.** Record both the surface area and the number of tons per station in the bituminous material "SEAL" column of the Typical Section Quantities Frame using the rounding criteria illustrated in Exhibits 13-1 and 13-2. Seal and cover is typically applied to mainline travel lanes, turn lanes and shoulders only. Discuss the need to apply seal and cover to approaches, and turnouts during the Plan-In-Hand.

3. **Tack.** Tack is slow-setting emulsified asphalt, used to help separate lifts of plant mix bond to each other, and to help bond plant mix overlays to underlying material. When tack is measured separately for payment, include quantities for the total surface area per station where tack will be applied, as well as the bid item quantity per station in the Typical Section Quantities Frame. Tack quantities are generally presented in gallons, measured by the amount of undiluted emulsion applied. For projects with aggregate treatment, include an application of tack on top of the treated aggregate, as well as between subsequent lifts of plant mix. It is acceptable to use the area at the bottom of the plant mix to estimate tack oil quantities for all lifts. Record the quantities in the bituminous material "TACK" column of the Typical Section Quantities Frame using the rounding criteria illustrated in Exhibits 13-1 and 13-2. See Appendix K for application rates and sample quantity calculations.

4. **Fog Seal**. A fog seal may be applied to the top of a seal and cover operation or to new or disturbed plant mix surfaces to improve durability. Materially, a fog seal is the same or very similar to tack, however the purpose and application rate(s) are different. When fog seal is measured separately for payment, include quantities for the total surface area per station where the fog seal will be applied, as well as the bid item quantity per station in the Typical Section Quantities Frame. Fog seal quantities are generally presented in gallons, measured by the amount of undiluted emulsion applied. Record the quantities in the bituminous material “FOG SEAL” column of the Typical Section Quantities Frame using the rounding criteria for tack illustrated in Exhibits 13-

1 and 13-2. See Appendix K for application rates and sample quantity calculations.

5. **Double Bituminous Surface Treatment (Double Shot)**. Application rates for this material are provided in Appendix K.
6. **Curing Seal.** A curing seal is typically placed on top of the CTB. CRS-2 oil is typically used for the curing seal. Record both the surface area and the number of tons per station in the "CURING SEAL" column of the Typical Section Quantities Frame. Curing seal is applied to the top of the Cement-Treated Pulverized Base at the same rate as it is applied to CTB.

13.5.2.3 Other Material Quantities

Materials that are neither bituminous nor aggregate in nature are generally included on the right side of the Typical Section Quantities Frame, as their method of measurement and calculations are similar to those of bituminous materials. Example calculations are provided in Appendix K.

1. **Aggregate Treatment.** Aggregate Treatment is applied to the top of otherwise untreated Crushed Aggregate. Record the surface area in square yards per station in the "AGGREGATE TREATMENT" column of the Typical Section Quantities Frame using the rounding criteria illustrated in Exhibits 13-1 and 13-2.
2. **Portland Cement.** For projects with Cement Treated Pulverized Base, the cement used is generally measured separately for payment. The Surfacing Design Section will provide the estimated cement content (by percent weight) used to calculate the tons per station. Current practice is to allow the contractor to substitute some amount of the Portland Cement with fly ash. In a case such as this, when the substitution is optional but the bid item remains Portland Cement, only show a quantity of Portland Cement assuming no substitution. If a fly ash content is specified and measured for payment, calculate the tons per station based on the specified fly ash content, and record that quantity in a separate column.

13.5.2.1 Portland Cement Concrete Pavement (PCCP)

Quantities

PCCP is measured by the square yard and rounded to the nearest 0.1 square yard. Fillets for widened sections or at drainage structures and similar locations placed monolithic with the pavement are measured as pavement. Areas constructed other than as pavement are deducted from the pavement area (e.g., gutter pan). Do not make any deductions for any fixtures located within the pavement limits that have a surface area of 1.0 square yard or less.

Where PCCP is specified, include the necessary details in the plans for the various types of joints and joint locations or patterns. Additional information is provided in the Joint Details discussion.

PCCP Types

The following are the two basic categories of PCCP:

1. **Plain-Jointed Pavement.** This PCCP has transverse joints without dowel bars. Load transfer across the joint is developed by aggregate interlock. Aggregate interlock relies on the interaction between aggregate particles at the irregular crack face that forms below the saw cut. MDT does not recommend the use of plain-jointed pavement for new construction, and has retrofitted existing plain-jointed pavements with dowel bars in some cases. Plain-jointed concrete may be approved for use on urban facilities with very low truck volumes, and for PCCP pavements less than 8 inches thick.
2. **Reinforced-Jointed Pavement.** This PCCP has transverse joints with dowel bars. Dowel bars are round, smooth steel bars placed across transverse joints to transfer loads without restricting horizontal joint movement due to thermal and moisture contractions and expansions. Dowel bars also keep slabs in horizontal and vertical alignment and reduce deflections and stresses due to traffic loads. Tie bars, made of deformed reinforcing steel, are used to tie slabs across longitudinal joints.

   Reinforced-jointed PCCP is applicable for new construction when PCCP is at least 8 inches or thick. Typical dowel and tie-bar size and spacing can be found in the *MDT Detailed Drawings*.

Joint Details

There are four general classifications of joints for PCCP. Joint types and their functions are briefly discussed below, while details are provided in the *MDT Detailed Drawings*:

1. **Transverse Joints**. Transverse joints are placed perpendicular to the roadway's centerline. These joints primarily control the natural transverse cracking due to contraction in the PCCP. Proper transverse joint design for both plain and reinforced pavements will specify the joint interval that will control cracks and provide adequate load transfer across joints.
2. **Construction Joints.** These joints are placed at planned interruptions (e.g., at the end of each day's paving, at intersections, where unplanned interruptions suspend operations for an extended period of time). Wherever practical, install the joints shown in the *MDT Detailed Drawings* at the location of a planned joint. These are butt-type joints that need dowels because there is no aggregate interlock to provide load transfer. Dowel size and spacing are the same as shown in the *MDT Detailed Drawings*. To perform properly, the dowel ends extending through the butt joint must include a bond breaker. If an unplanned construction joint occurs in the middle two-thirds of the normal joint interval, use a keyed joint as shown in the *MDT Detailed Drawings* with tie-bars instead of dowels.
3. **Longitudinal Joints.** Longitudinal joints are placed parallel to the roadway's centerline. These joints primarily control longitudinal cracking developed from the combined effects of load and restrained warping after pavements are subjected to traffic. On two-lane and multilane roadway pavements, a

spacing of 10 feet to 13 feet serves the dual purpose of crack control and lane delineation.

The longitudinal construction joint shown in the *MDT Detailed Drawings* is typically used for one lane-at-a-time construction. This includes adjacent lanes, shoulders, and curb and gutters. This joint may or may not be keyed depending on the slab thickness, lateral restraint and traffic volumes. The longitudinal contraction joint shown in the *MDT Detailed Drawings* is used where two or more lanes are paved at a time. With slip-form paving, two-, three- or four-lane pavements can be placed in one pass. These joints depend on the tie-bar to maintain aggregate interlock, structural capacity and serviceability.

4. **Isolation Joints**. Isolation joints are placed around in-pavement structures (e.g., drainage inlets, manholes, lighting structures). These joints primarily lessen compressive stresses that develop between the pavement and a structure or between two pavement sections. See the *MDT Detailed Drawings* for a typical isolation joint.

   Isolation joints used at structures (e.g., bridges) should have dowels to provide load transfer and increase pavement performance. See the *MDT Detailed Drawings* for detail of doweled isolation joints.

Jointing Layout

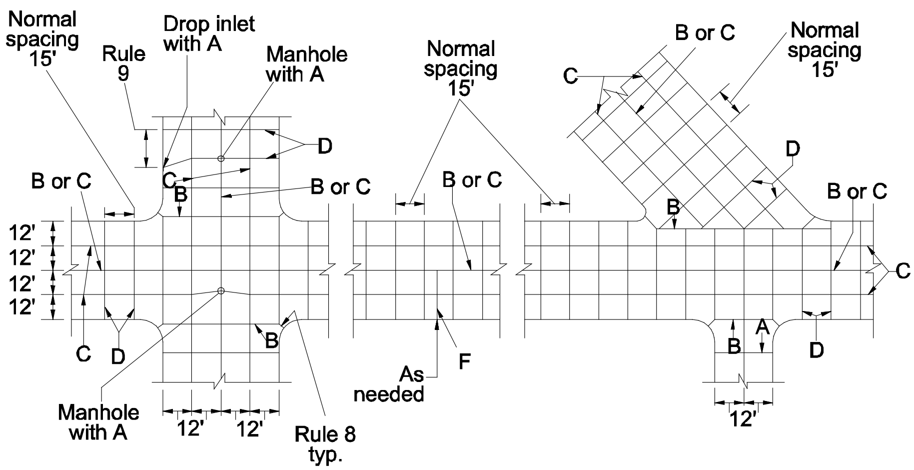
A well-designed jointing layout can eliminate unsightly random cracking, can enhance the appearance of the pavement and can provide years of low maintenance service. The following recommendations will help in the design of a proper jointing system.

1. Avoid odd-shaped slabs, including triangles and narrow rectangular sections. Avoid joint intersection angles less than 60 degrees.
2. Maximum transverse joint spacing should either be 24 times the slab thickness or 15 feet, whichever is less.
3. Longitudinal joint spacing should not exceed 12.5 feet. Locate longitudinal joints at or near the edge of the lane when possible.
4. Keep slabs as square as practical. Long narrow slabs tend to crack more than square ones. Limit the slab length to width ratio to 1.5 or less if practical.
5. All transverse contraction joints must be continuous through the curb and have a depth equal to 25 percent to 33 percent of the pavement thickness depending on the subbase type.
6. In isolation joints, the filler must be full depth and extend through the curb.
7. Tie longitudinal joints with deformed tie-bars.
8. Offsets at radius points should be at least 1.5 feet wide. One method is to widen or vary the width of the gutter pan, so that adjacent slabs can remain square.
9. Minor adjustments in joint location made by shifting or skewing to meet inlets and manholes will improve pavement performance.

10. Where the pavement area has drainage structures, place the joints to meet these structures, if practical.

A typical joint layout detail is shown in Exhibit 13-3.

Exhibit 13-3
Pavement Joint Details



A, Isolation joints
B. Longitudinal construction joints
C. Longitudinal contraction joints
D. Transverse contraction joints
E. Planned transverse construction joint
F. Emergency transverse construction joint

13.5.3 Surfacing Quantities (Summary Sheet)

When calculating the quantities for the Surfacing and Additional Surfacing Frame on the Summary Sheets, consider the following guidelines:

1. **Typical Section Quantities.** For each typical section that has a Typical Section Quantities Frame, multiply the quantities by the net number of stations and record the values in the Surfacing Frame. Do not include bridge lengths, as measured from the bridge end bents' centerline-of-bearing to centerline-of-bearing, in the net length. Provide a separate line in the Surfacing Frame each time the typical section used to calculate quantities changes. Quantities between the transition of two typical sections should also be recorded on a separate line. Estimate transition quantities by multiplying the transition length, in stations (Sta.), by the average quantity of surfacing in the two typical sections.
2. **Bridges.** Any surfacing of bridges must be approved by the Bridge Bureau. The thickness of plant mix material allowed on bridge decks is based on the structural capacity of the bridge.
3. **Hydrated Lime**. Typically, hydrated lime is used to treat plant mix surfacing materials, including RAP. Estimate the quantity of hydrated lime at 1.4 percent of the mass of plant mix and record the total in the Surfacing Frame on the Summary Sheets. Hydrated Lime is not calculated for projects that are utilizing commercial plant mix.

4. **Additional Surfacing Frame.** Use the Additional Surfacing Frame to record the surfacing quantities for approaches, connections to present travel way (PTW), leveling, and other surfacing quantities not represented in the quantity frames of the typical sections. The quantity totals from the Additional Surfacing Frame are recorded on the bottom of the Surfacing Frame and added to the Surfacing Frame totals.
5. **Approach Surfacing Quantities**. Chapter 6 presents MDT's criteria for approaches. In addition, Appendix K provides additional information and examples. In addition, the design team should consider the following guidelines:
    a. **New Construction or Reconstruction Projects.** Pave public and private approaches to the right-of-way line. Farm field approaches will be surfaced with gravel to the right-of-way line and will receive a 12 feet plant mix strip adjacent to the roadway. The decision whether to seal and cover approaches will be determined at the Plan-in-Hand.
    b. **Overlay and Overlay/Widening Projects.** All public approaches will be overlaid to the radius returns or the right-of-way line. On all paved private approaches and all farm field approaches having a paved width of 12 feet, provide a 3 feet plant mix strip. This strip serves as a transition and reduces the edge-breaking potential of the new pavement.
    c. **High-Volume Approaches.** Approaches with high volumes of traffic, particularly truck traffic, may require special designs. The surfacing design and layout should be discussed with the Surfacing Design Section and the Geometric Design Section during the development of the project.
    d. **Frame Listing.** Total the surfacing required for all of the approaches for each type of approach and record each total on a separate row in the Additional Surfacing Frame. Approaches that require a lengthy or different surfacing section also should be recorded separately in the Additional Surfacing Frame.

13.5.4 Miscellaneous Roadway Quantities

This section provides guidance for miscellaneous roadway quantities.

13.5.4.1 Pavement Markings

The Traffic and Safety Bureau is responsible for determining both interim and final pavement marking quantities. The design team is responsible for recording each in the Pavement Marking Frame on the Summary Sheet. When a Seal and Cover operation is included with the project, a quantity for Final Sweeping and Brooming is shown in the Pavement Marking Summary. The quantity for Final Sweeping and Brooming is measured by the two-lane course mile, and is prorated for auxiliary lanes.

The design team is responsible for determining the quantities required for temporary pavement markings. Estimate the quantities for each of the following paving operations:

1. Each lift of pavement – for estimating purposes lift thicknesses are between 0.15 feet and 0.20 feet inclusive
2. A milled surface
3. Isolations lifts

An additional quantity of temporary pavement markings may also be required for the existing pavement. The need for additional quantities will be determined by District Construction personnel. Temporary pavement markings are not needed for normal leveling. Compute the quantities for temporary pavement markings for each two-lane mile of the project.

13.5.4.2 Guardrail

Chapter 9 presents MDT's criteria for guardrail placement. Station limits for guardrail will include the terminal sections and bridge approach sections. Guardrail is measured from center-to-center of the end posts of each section along the guardrail's actual location and quantity calculations should reflect the following information:

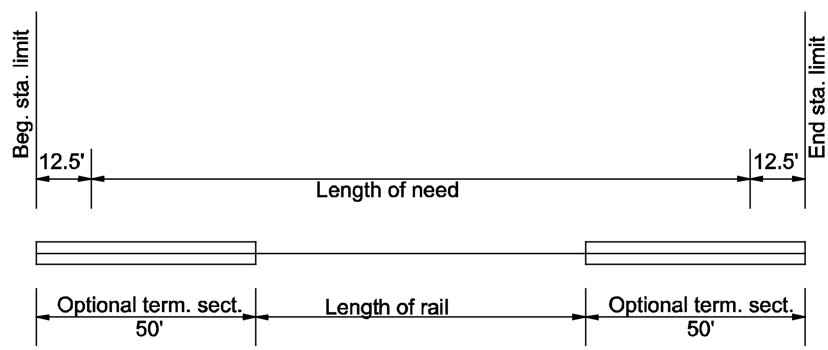
1. **W-Beam Guardrail Quantities**. Due to manufacturing criteria, compute the length of need and round up to the next highest multiple of 12.5 feet. If room is available, multiples of 25 feet are preferred.
2. **Low-Tension Cable Guardrail Quantities**. Compute the length of need and round up to the next highest multiple post spacing. Post spacing on tangents and curves with radii greater than 720 feet is 16 feet. Post spacing on curves with radii less than 720 feet and greater than or equal to 440 feet is 12 feet. Do not install cable guardrail on the outside of curves with radii less than 440 feet or on the inside of any curve.
3. **Box Beam Guardrail Quantities**. Due to manufacturing criteria, compute the length of need and round up to the next highest multiple of 18.0 feet.
4. **Concrete Barrier Rail.** Due to manufacturing criteria, compute the length of need and round up to the next highest multiple of 10 feet. Concrete barrier rail is paid at the unit price bid for each 10 feet increment.
5. **Raise Guardrail.** Use the pay item "Raise Guardrail" only when the existing rail has a predrilled hole in the post for that reason. See the Detailed Drawings for criteria on the height for when raising guardrail is appropriate. If the existing rail cannot be raised, it should be removed and replaced by new, or reset.
6. **Remove Guardrail**. Compute actual quantity of guardrail to be removed.
7. **Reset Guardrail.** Reset Guardrail is used to adjust guardrail that is too low, but is otherwise in good condition, to the proper height when it cannot be raised as described above. Terminal sections that are reset are bid separately per each. The remaining run is measured up to the nearest 12.5 feet. Guardrail that does not meet current requirements cannot be reset (e.g., concrete posts).

8. **Bridge Approaches.** Bridge approach sections are included in the station limits, but are bid as a separate unit. Therefore, they are not included in the length of rail. Ensure the type of bridge approach section specified matches the bridge rail. See the *MDT Detailed Drawings* for the application of each type of bridge approach section. Box beam guardrail can only be connected to Wyoming Bridge Rail. The design team should contact the Bridge Bureau for the type of bridge rail in place or to be installed.

9. **Terminal Sections**:

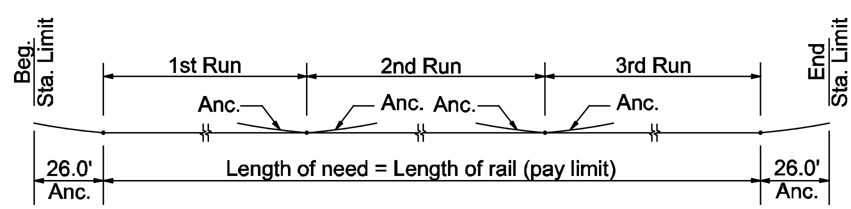
   a. W-Beam Guardrail. The optional terminal sections and one-way departure terminal sections are included in the station limits but are separate bid items; therefore, it is not included in the length of rail. See Exhibit 13-4 for computing guardrail lengths with Optional Terminal Sections.

Exhibit 13-4
Optional Terminal Section



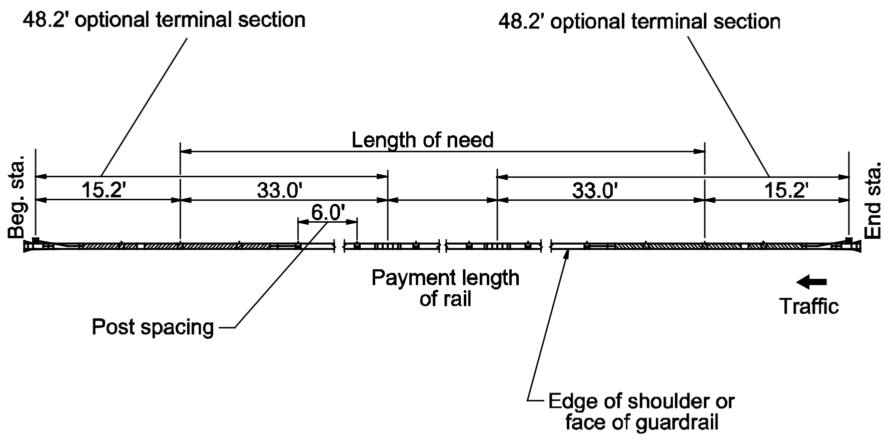
   b. Cable Guardrail. Note that the maximum run of low tension cable guardrail is 2,000 feet (excluding terminal sections); see the *MDT Detailed Drawings*. Therefore, with a long run of cable guardrail, there may be several terminal sections. See Exhibit 13-5 for computing the length of cable guardrail.

Exhibit 13-5
Cable Guardrail



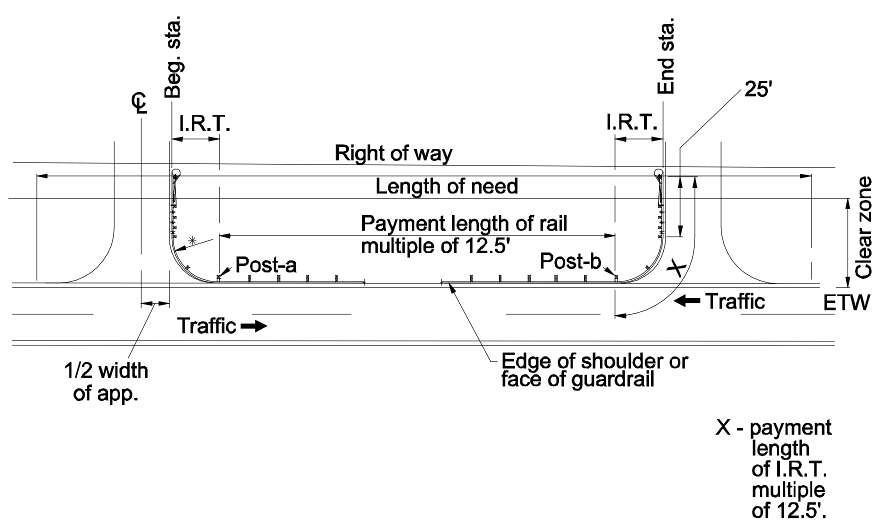
   c. Box Beam Guardrail. The box beam optional terminal sections and one-way departure terminal sections are included in the station limits but are separate bid items; therefore, they are not included in the length of rail. See Exhibit 13-6 for computing length of box beam guardrail.

Exhibit 13-6
Box Beam Guardrail



10. **End Anchors**. End anchors are not bid separately, but are included in the cost of the terminal section.
11. **Intersecting Roadway Terminal Section**. For intersecting roadway terminal (IRT) sections, the length of the IRT rail is bid separately from the rest of the guardrail. The station limits of the IRT should extend from the guardrail connection to the end of the IRT. Because the IRT is installed on a radius, the station limits do not reflect the length of the IRT rail. See the *MDT Detailed Drawings* for the selection of radii that will result in 12.5 feet increments of rail. Do not use intersecting roadway terminal sections with box beam rail. Exhibit 13-7 provides additional details on intersecting roadway terminal sections.

Exhibit 13-7
Intersecting Roadway Terminal Sections



12. **Impact Attenuators**. Using the manufacturer's guidelines, determine the number of bays required based on the design speed at the site. Impact attenuators are included in the station limits of the guardrail, but are a separate bid item. The entire impact attenuator system is bid as a unit (i.e., each).

13. **Stiffened Guardrail Sections.** Stiffened guardrail sections are used to shield an obstacle where dynamic deflection must be limited. See the *MDT Detailed Drawings* for configuration on one-way and two-way roadways, as well as required length and pay limits of stiffened guardrail.

13.5.4.3 Curb and Gutter

Chapter 5, Section 5.2.8 provides MDT criteria for curb and gutter sections. Show the curb and gutter station limits in the Curb Frame from the beginning of one curb return to the beginning of the next curb return (BCR to BCR). Chapter 6, Exhibit 6-3 illustrates the location of the BCR. In addition to the length of the curb and gutter between BCRs, the distance of the curb and gutter around the radius to the end of the curb return must also be included in the summary quantities. Radii dimensions are to the back of curb; however, the length is measured to the face of curb.

13.5.4.4 Sidewalks

Chapter 5, Section 5.2.9 provides MDT criteria for sidewalks. Sidewalk stations are recorded in the same manner as curb and gutter. For each depth of sidewalk in the project, compute the sidewalk area in square yards and round to the nearest 0.1 square yard. Report the results in the Sidewalk Frame. The cost for the aggregate base is incorporated in the unit cost per square yard of sidewalk. For sidewalk sections under vehicular traffic (e.g., intersections with approaches and alleys), use a 6-inch sidewalk depth. For all other locations, use a 4-inch sidewalk depth. Curb ramps are included in the 4-inch sidewalk quantities and are not a separate bid item. For areas where detectable warning devices (DWD) are used, the sidewalk under the DWD is included in the sidewalk quantity. The curbing around the curb ramp is paid for as curb and gutter and is typically included in the curb radii of curb and gutter; see Section 13.5.4.3.

13.5.4.5 Detectable Warning Devices

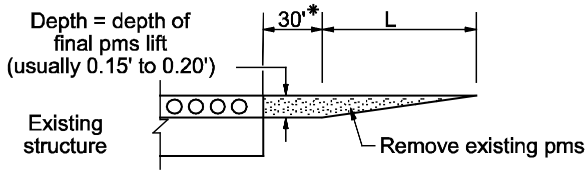
Detectable warning devices are a standardized detectable warning surface for sight-impaired pedestrians. The detectable warning devices are installed in the sidewalk ramp adjacent to the roadway and provide a cue that the pedestrian is moving from a pedestrian area to a vehicular area. Projects are required to install detectable warning devices on all new curb ramps and any project involving alterations to existing ramps.

The detectable warning devices are two feet wide, and are located at the bottom of the curb ramp and extend the width of the ramp. Detectable warning devices will be measured and paid by the square yard. Show the quantities for detectable warning devices in a separate column in the Sidewalk Summary. Refer to the *MDT Detailed Drawings* for more complete information.

13.5.4.6 Cold Milling

Cold milling is used to remove a specified depth of pavement. Where the pavement has deteriorated, the removal of all pavement above the plane of failure may be necessary prior to placing a new overlay. For these cases, the depth of milling will be determined by the Surfacing Design Section. A tapered depth cold milling connection is also used in conjunction with overlays to match the new surfacing elevations to existing bridge decks, railroad crossings, cattle guards and connections to existing pavement. Exhibit 13-8 provides an example of cold milling taper.

Exhibit 13-8
Cold Milling Taper Example



*Add the following note to the Detail Sheet in the contract plans: “Actual removal distances to be determined during construction by the Engineer.”

See Appendix K for additional information and to determine the extent of milling beyond the bridge ends. If taper milling has been used to tie a previous overlay to the bridge end, L must be calculated for both overlay thicknesses. For cattle guards, the pavement is typically milled for 65 feet (15′ of full depth milling and 50′ of taper milling) on either side of the structure. Review the application of this criterion during the Plan-In-Hand field review. Standard milling widths are 6.25 feet, 12.5 feet and 14.0 feet. Use the bottom width of the milled surface to compute the cold milling area and round to the nearest square yard. Where milling depth tapers are needed, use the maximum width (e.g., width at the bottom of the milled surface) to calculate the cold milling area. Record the results in the Cold Milling Frame.

13.5.4.7 Pavement Pulverization

Pavement pulverization is used to produce a uniform material for the total subgrade width by mixing the existing bituminous pavement with aggregate. Specify the depth of pavement pulverization based on Surfacing Design recommendation. The depth of the pulverization is the average depth of the existing bituminous pavement (the maximum depth is typically 0.66 feet). Use the bottom width of the pulverized surface base at the specified depth to compute the quantity of pavement pulverization. Calculate the area in square yards. Record the results in the Pulverization Frame.

Achieving a blend of pulverized plant mix and untreated aggregate surfacing is important. Pulverized plant mix should comprise 60 percent of the mix, while the remainder should be underlying base gravel, new aggregate blended during pulverization, or a combination of the two. Aggregate added to the pulverized material for leveling is measured by the ton. Record the results in the Surfacing Frame. Provide a design profile grade where pavement pulverization is specified. The design profile grade should be adjusted as necessary to account for leveling and swell of pulverized material.

13.5.4.8 Finish Grade Control

Record finish grade control staking quantities in the Finish Grade Control Frame on the Summary Sheets. Also consider the following:

1. Each course foot of finish grade control staking is based on a 2-lane roadway, including shoulders and ditches.
2. Each traffic lane, ramp, climbing lane, etc., is one-half of a course foot for measurement. Do not measure parking lanes, turning lanes, median lanes and chain-up areas separately from the adjacent roadway.
3. Four-lane facilities require separate measurements for each direction of the roadway.
4. Measure the subgrade and each base course of aggregate requiring finish grade control staking separately, by the course foot, for each roadway, ramp, intersecting roadway, PTW connection, temporary detour and frontage road.
5. For facilities with aggregate surfaces, finish grade control is only provided for the subgrade if the aggregate is paid for by the ton. However, finish grade control is provided for both subgrade and aggregate surfacing if the aggregate is paid for by the cubic yard. A separate course of finish grade control staking will be required where special borrow is used.
6. Take measurements along the centerline of each roadway and round to the nearest 50 feet.

13.5.4.9 Traffic Gravel

Traffic gravel is used as temporary surfacing to carry traffic on stages of unfinished grading (e.g., cuts or fills). For the areas where the traffic cannot be maintained on the PTW or finished subgrade, determine the number of stages the cut or fill will be constructed. Compute the quantity of traffic gravel based on the following criteria:

1. 24-foot minimum travel width,
2. 0.20 feet depth of traffic gravel, and
3. the length of temporary surfacing.

Verify traffic gravel quantities with District construction personnel. Traffic gravel is measured and paid by the cubic yard or ton. Round the calculated quantity to the nearest cubic yard or ton and record the quantity in the "TRAFFIC GRAVEL" column of the Surfacing Frame.

13.5.4.10 Rumble Strips

Rumble strips should be installed in accordance with *MDT Rumble Strip Guidance* and in conjunction with the *MDT Detailed Drawings* or project plan details. When calculating rumble strip quantities, consider the following guidelines:

1. Each individual line of rumble strips is measured separately for payment.
2. Deduct gaps for bridges, ramps, and approaches from the length quantity for rumble strips.

3. Discontinue rumble strips on shoulders less than 6 feet wide if guardrail exists or is proposed. For other locations to discontinue rumble strips, the design team should refer to the *MDT Rumble Strip Policy*
4. Take measurements along the centerline of the roadway and round to the nearest 0.1 miles.
5. Record the rounded quantity in the Rumble Strips Frame.
6. On all projects that have shoulder rumble strips, calculate a quantity of fog seal to be applied to the rumble strips. Use SS-1, applied to a width of 2 feet at an undiluted application rate of 0.05 gal/yd^2. Show this quantity for informational purposes. The cost of the fog seal is included in the cost of the rumble strips.
7. The *MDT Detail Drawings* show a Centerline Rumble Strips (CLRS) detail and should be used in all locations where CLRS are specified, unless documented in the Scope of Work Report for use of a different design.

13.6 MISCELLANEOUS COMPUTATIONS

13.6.1 Lump Sum Items

Use lump sum bid items where the scope of work for the item is clearly defined and the amount of work has a minimal chance of changing during construction. Lump sum should also be considered where the end result is defined, but there are various methods of achieving the desired results. Including an item of work in another item should only be done where the scope of work for each item is clearly defined and the chance of the quantity of either item changing is minimal. Where practical, list separately the quantities that comprise the lump sum item of work. The list should note that the "quantities are for estimating purposes only." Provide a clear definition of work for each item whether it is bid by the unit, included in the cost of other items, or bid lump sum. Where there is a significant chance of quantity change, the work should be bid by the unit. Where lump sum items are used, the total quantity for the project should always equal one. If more than one item or location is included in the lump sum, show the decimal proportion of the work of each location. For example, for a project which includes the removal of three structures being 30 feet, 30 feet, and 60 feet long, the proportion would be 0.25, 0.25, and 0.50, respectively.

13.6.2 Clearing and Grubbing

Clearing and grubbing is typically included in the construction plans and, generally, will not require a separate set of plan sheets. Decisions related to the payment method (e.g., lump sum, absorbed in other bid items, by the acres) should be made during the Plan-in-Hand field review. Payments based on the number of acres involved require the quantities to be presented on the Clearing and Grubbing Frame. Where clearing and grubbing will be included in the grading bid item, include an appropriate note in the Notes Sheet. Clearing and grubbing may be bid either as separate bid items with different bases for payment or as a single item. If the clearing and grubbing has separate phases, the quantities for each should be shown separately in the summary and the special provisions should describe the measurement and payment for each phase. The decision on the disposition and areas of selective cutting will be made at the Plan-in-Hand field review. The disposition of merchantable timber should be determined during right-of-way negotiations.

13.6.3 Topsoil

In general, topsoil will be required on most projects. The design team should review the following relative to the placement of topsoil:

1. **Topsoiled Areas**. Provide topsoil according to the following guidelines:
    a. Topsoil will be required on all projects where the existing topsoil is disturbed. Where topsoil is impractical to salvage or is unsuitable (e.g., rock cut), eliminate the area from the topsoil salvage quantity. Also provide a special provision describing the special slope treatment to be used.
    b. Provide topsoil on all 2:1 or flatter slopes.
    c. Place topsoil on the gravel surfacing inslope to the edge of the plant mix for all projects that involve disturbance of the inslope as per the *MDT Detail Drawings*.
2. **Topsoil.** Assume that the existing topsoil will be salvaged and stockpiled unless otherwise noted.
3. **Placement.** Where required, provide topsoil to a loose depth of 4 inches from the bottom edge of the plant mix to the catch point.
4. **Quantities.** Use the following procedure to compute topsoil quantities and record them on the summary sheets:
    a. Topsoil quantities should be based on a 4-inch depth over the area of the constructed slopes requiring topsoil placement.
    b. Show topsoil quantities, in cubic yards, in 3,000 feet increments in the Topsoil and Seeding Frame.
    c. Topsoil quantities can be obtained using computer-generated data or manually calculated computation sheets.

13.6.4 Seeding

Where seeding is provided on a project, consider the following guidelines:

1. **Seeded Areas.** Provide seeding on all slopes extending from the edge of plant mix to the new right-of-way limit, except on slopes steeper than 1.5:1, areas that are predominantly rock, and other locations that are difficult to grow grass.
2. **Determining Quantities.** The Environmental Services Bureau is responsible for determining the seed type, seeding rate, amount of fertilizer and mulch used per acre. Generally, different seeding rates will be specified for:
    a. The total area to be seeded inside the new right-of-way having 3:1 or flatter slopes (Area 1) minus the areas described below,

b. Constructed slopes steeper than 3:1 (Area 2),

c. A strip extending from a point from the edge of the plant mix to a distance of 15 feet or to the edge of the surfacing inslope, whichever is greater (Area 3), and

d. Other specified areas.

The design team will be responsible for determining the size of the area to be seeded at each rate using computer generated data or manually calculated computation sheets. The number of acres in Area 1 that require seeding are calculated as follows:

Area 1 = Right-of-Way - Area 2 - Area 3 - Surface Area

Where:

Right-of-Way = The total area inside the new right-of-way

Surface Area = (Finished top width) x (length of project)

No fertilizer is required for Area 3.

3. **Recording Quantities**. Record the seeding areas in the Topsoil and Seeding Frame. The seeding areas should be recorded as follows:

    a. Present the number of separate acres for areas on slopes of 3:1 or flatter, areas on slopes steeper than 3:1, the 15 feet wide strip adjacent to the edge of pavement and for other areas defined in the seeding recommendations.

    b. For Area 1 and Area 3 seeding conditions, provide areas of seed bed conditioning in acres. Mulch, in acres, is generally provided for Area 2 conditions.

13.6.5 Fencing

The *MDT Detailed Drawings* present MDT criteria for the design and placement of fencing. For quantity estimating, consider the following guidelines:

1. **Fence Types.** Refer to the Right-of-Way agreements to determine the type of fence required. Fencing is typically measured to the nearest foot. The length of fence does not include cattle guards, gates or other openings. These items are paid for separately.

2. **Temporary Fencing.** The length around the construction permit areas should be used to determine the quantity of temporary fence.

3. **Panels.** See the *MDT Detailed Drawings* to determine the type and number of fence panels that should be used with a run of fencing.

4. **Deadmen.** For estimating purposes, include the following number of deadmen per mile of fence based on the type of terrain:

    a. Flat terrain — 2 deadmen per mile of fence

    b. Rolling terrain — 5 deadmen per mile of fence

    c. Rough terrain — 8 deadmen per mile of fence

5. **Gates.** Most gates used by MDT should be measured in 2 feet increments.

6. **Recording.** Include all fencing quantities in the Fencing Frame. List the fence lengths for the left side of the roadway from the beginning station to ending station, and then for the right side from beginning to ending station. Terminate the stationing at each parcel (per the Right-of-Way agreements), change in fence or post type, gates, cattle guards, or other openings. Also include the following information in the fencing summary:
   a. The "FENCE TYPE" column heading should include the post designation (e.g., F4M, F4W) where:

      M = metal posts

      W = wood posts
   b. Call out the gates by station at each end of the gate and list them according to type.
   c. Show totals only for temporary fence and deadmen.
7. **Fencing Plans.** If requested by the District, prepare fencing plans on a set of white prints of the right-of-way plans. The *MDT Detailed Drawings* show how the fencing plans should be prepared. Do not include the fencing plans in the contract package, but transmit them to the District at the time of the project letting.

13.6.6 Cattle Guards

The *MDT Detailed Drawings* present MDT criteria for the design and placement of cattle guards. For quantity measurements, note that cattle guards are available in two standard sizes: 10′ by 8′ and 12′ by 8′. For most roadways, two 12′ by 8′ cattle guards will provide an adequate design. In all cases, extend the cattle guard fully across the finished surface width, including finished shoulders. Itemize the number of cattle guards in the Cattle Guard Frame.

13.6.7 Concrete Slope Protection

Design concrete slope protection, used for bridge end slopes, as shown in the *MDT Detailed Drawings*. Estimate quantities of concrete slope protection in square yards of concrete rounded to the nearest 0.1 square yard.

13.6.8 Detours

During the construction of a project, a detour often is constructed, maintained and removed. Provide sufficient details for all detours on a project. The details include the plan and profile of the detour, the typical section of the detour, the design speed of the detour and a list of the components and quantities necessary to construct the detour. The quantities are for informational purposes only. The construction, maintenance and removal of the detour will be paid either per each or as a lump sum bid item. Chapter 10 provides additional information on detour details. Include the detour typical section with the project typical sections.

Waterway openings for detours will consist of recommendations from the Hydraulics Section for a specific drainage structure (e.g., pipes, bridge), or a statement in the special provisions that the contractor will provide an adequate waterway opening for the detour. Include the cost of any required drainage structures in the lump sum or per each bid for "Construct, Maintain and Remove Detour."

13.6.9 Considerations for Grading with Rock

Material requiring ripping or production blasting is included in the regular excavation quantities for the project, and no separate or additional method of measurement is used. When formation material is encountered at the design subgrade, a six inch depth of subexcavation, called "excavation below grade", is required and measured for payment. Unclassified soil is used to backfill areas of excavation below grade, and the quantities are typically identified in the Additional Grading Frame with equal volumes of cut and fill.

Rock slope stabilization projects and projects with rock excavation may require quantities for trim blasting, rock scaling, rock bolting, or rock slope mesh to reduce or mitigate the potential for rock fall reaching the roadway. The need and quantities for these items will be determined by the Geotechnical Section.

13.6.9.1 Pre-Splitting Rock Slopes

Pre-splitting rock cuts is used to produce a continuous or semi-continuous fracture between drill holes and a stable rock cut, and to eliminate overbreak in the backslope during primary blasting. Pre-splitting rock cut to a smooth plane is achieved by detonating evenly spaced holes prior to detonation of the production holes. Pre-splitting rock cuts will be recommended by the Geotechnical Section, if needed.

Drill pre-splitting holes are measured by the foot for each hole. The measurement is made from the rock surface to the roadway grade or to a predetermined bench elevation. A 30-inch interval is used to estimate the number of drilling pre-splitting holes. Record the computed length of holes in the Drill Pre-Splitting Holes Frame.

13.7 COORDINATION

The design team should refer to current MDT specifications, supplemental provisions, and design memos, to ensure the project quantities they include in the plans meet the current state of the practice for measurement and payment.

13.8 REFERENCES

1. Montana Department of Transportation (MDT). *Standard Specifications.* MDT, Helena, MT, 2014.
2. MDT. *Geometric Design Standards.* MDT, Helena, MT, 2016.

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 14

Specifications/Special Provisions/Detailed Drawings

September 2016

Contents

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Chapter 14

Specifications/Special Provisions/Detailed Drawings

Chapter 12 presents Montana Department of Transportation's (MDT) procedures for the preparation of construction plans. In addition, contractors, material suppliers, and MDT personnel assigned to supervise and inspect construction use the *Standard Specifications for Road and Bridge Construction (Standard Specifications)*, Supplemental Specifications, Special Provisions and the *MDT Detailed Drawings* to assist them in the project design and construction. The Montana Public Works Specifications may also be used, particularly for urban projects and projects involving water lines and sanitary sewers. Chapter 14 describes the purpose of the Specifications, Special Provisions and Detailed Drawings. Chapter 14 also presents the guidelines for preparing Special Provisions.

The current *Standard Specifications,* Supplemental Specifications, Standard Special Provisions, and *MDT Detailed Drawings* are all available on the MDT Website. Links to these documents are provided below. Supplemental Detailed Drawings are incorporated into the electronic copies of the Detailed Drawings, and only differ as they are modified or added since the last "publishing".

14.1 GENERAL INFORMATION

14.1.1 Hierarchy of Importance

The *Standard Specifications*, Supplemental Specifications, *MDT Detailed Drawings*, Special Provisions, and construction plans are all essential parts of the contract. They are intended to complement each other and are used to describe and provide complete instructions for the work to be accomplished. If a discrepancy does exist between these documents, the following presents the hierarchy of importance among them:

1. "Question and Answer Forum" Information
2. Special Provisions
3. Table of Contractor Submittals
4. Plans
5. Supplemental Specifications
6. *Standard Specifications*
7. Supplemental Detailed Drawings
8. *MDT Detailed Drawings*

14.1.2 "Question and Answer Forum" Information

This is a forum for Contractors to submit questions they have about the advertised Contract Package that can be seen by all plan and specifications holders. MDT's "Question and Answer Forum" can be found at the following link on the MDT Website:

MDT "Question and Answer Forum"

14.1.3 Special Provisions

Special Provisions are additions or revisions to the *Standard Specifications* and the Supplemental Specifications setting forth conditions and requirements for a special situation on a particular project. Special Provisions are included in the contract documents for a specific project, and are not intended for general use. The design team prepares them for inclusion into the project documents. The Special Provision should also include the appropriate section number from the *Standard Specifications* (e.g., COLD MILLING [411]). Note that the section number is in brackets rather than parentheses. Section 14.2 discusses guidelines for preparing Special Provisions.

Standard Special Provisions are Special Provisions that are commonly applicable to many projects. The Contract Plans Bureau has compiled a list of Standard Special Provisions for road and bridge items. This list is routinely updated and can be obtained from the Contract Plans Bureau. The design team is responsible for calling out the number and title of the Standard Special Provisions that apply to road design items (e.g., No. 401-10 Fog Seal). Standard Special Provisions that require modification will have an "m" located after the date of initiation or revision. (e.g., 108-14 Sequence of Operations Revised 5-5-03 m). The design team should not send the text of the Standard Special Provision unless it contains revisions. The revisions should be highlighted. The design team must ensure that they are applicable for the particular project before their inclusion in the contract document. MDT's Standard Special Provisions can be found at the following link on the MDT Website:

MDT Standard Special Provisions

14.1.4 Table of Contractor Submittals

The Table of Contractor Submittals is a Special Provision that provides directions to the contractor on the required submittals for approval throughout the execution of the contract. The table may not be all-inclusive and does not include submittals required by other Special Provisions. All submittals required by the contract, including those not listed in the table, are to be provided by the contractor. If a discrepancy exists, submittals required by other Special Provisions in the contract take precedence over the Table of Contractor Submittals.

Additional information regarding the Table of Contractor Submittals can be found in the MDT Specifications Book and at the following link on the MDT Website:

MDT Table of Contract Submittals

14.1.5 Specifications

14.1.5.1 Standard Specifications for Road and Bridge Construction

The *Standard Specifications for Road and Bridge Construction (Standard Specifications)* are standards adopted by MDT for work methods and materials that are used for construction. The *Standard Specifications* are part of all construction contracts. They provide MDT's criteria for:

1. Bidding,
2. Awarding of the contract,
3. The contractor's duties,
4. Controlling the material quality,
5. The contractor and MDT's legal requirements,
6. Executing the contract, and
7. Measuring and paying for contract items.

The *Standard Specifications* are published in book form and are typically updated and reprinted every five to seven years. Copies of the *Standard Specifications* can be obtained from the Contract Plans Bureau.

A Standard Specification Revision Form must be submitted for all proposed changes to the *Standard Specifications* and addressed to the Construction Administration Services Bureau for evaluation and action. If changes are approved they become supplemental specifications.

MDT *Standard Specifications* can be found at the following link on the MDT Website:

MDT Standard Specifications

14.1.5.2 Supplemental Specifications

Supplemental Specifications are additions, deletions, and/or revisions to the *Standard Specifications* that have been adopted by MDT since the last printing of the *Standard Specifications*. The intention is that they will be incorporated into the

Standard Specifications at the next revision. As indicated in Section 14.1.1, Supplemental Specifications supersede the *Standard Specifications*. Complete sets of Supplemental Specifications are added to the contract documents for all projects.

Supplemental Specifications are typically updated and reprinted in their entirety every two months. Copies of the latest versions can be obtained from the MDT Website (see Section 14.1.5.1 for Website link) or Contract Plans Bureau.

14.1.6 MDT Detailed Drawings

The *MDT Detailed Drawings* provide details on various design elements that are consistent from project to project (e.g., guardrail, fencing, drainage details). They provide information on how to layout or construct the various design elements. A hard copy of the *MDT Detailed Drawings* is provided to the contractor upon request and is also provided at the following link on the MDT Website:

MDT Detailed Drawings

The Contract Plans Bureau will provide updated hard copy versions on an as-needed basis. All proposed changes to the *MDT Detailed Drawings* must be addressed to the Construction Administrative Services Bureau for evaluation and action. Any changes to the detailed drawings that are approved are included in the electronic files and are considered supplemental detailed drawings until the complete set is reissued.

Note that the first three numbers of the detailed drawing number are coordinated with the *Standard Specifications*. For example, Detailed Drawing No. 606-05 "Metal Guardrail" is referenced to Section 606 "Guardrail, Median Barrier Rail and Guide Post" in the *Standard Specifications*.

Users can download and review the drawings on the MDT Intranet or MDT Internet Web page (Contractor's System). However, the design team will be unable to make changes to these files. In addition, all drawings are available on MDT's Computer-Aided Design and Drafting (CADD) system. These CADD files can be copied and modified to make project specific details as necessary to be included in the plans.

14.2 SPECIAL PROVISION PREPARATION

Special Provisions are required whenever a project contains work, material, sequence of operations, or any other requirements that are necessary for the completion of the project, but are not "described completely" in the construction plans, *Standard Specifications*, Supplemental Specifications or the *MDT Detailed Drawings*. The term "described completely" should be interpreted to mean that the prospective bidder will be able to clearly understand the work to be accomplished, type of materials or equipment required, construction methods or details to be used, how the item of work will be measured, and the basis of payment. A Special Provision is also required for any experimental feature included with a project.

An overview of MDT's experimental features process is provided on the MDT website at the following link:

[Experimental Projects Overview]

The following sections provide guidelines for preparing Special Provisions.

14.2.1 Preparation Steps

Do not prepare Special Provisions using the "cut-and-paste" method. Instead, the design team should use the following steps when preparing a Special Provision:

1. **Define Need**. Review existing specifications, detailed drawings or construction plans to ensure that there is a need for the Special Provision. If the topic is not adequately covered in one of the other contract documents, only then should a Special Provision be prepared.
2. **Research.** Research the topic so that complete and detailed information is available before writing the Special Provision. This may require contacting manufacturers, contractors, or suppliers for the latest information. Local conditions and problems should also be fully investigated.
3. **Format.** Prepare Special Provisions in the same manner as the *Standard Specifications*. Section 14.2.2 presents the format that should be used.
4. **Type.** Analyze the type of construction to be covered in the Special Provision to determine the type of Special Provision to be used. There are two basic ways to present Special Provisions: by materials and methods, and by performance presentation. The *materials or methods* presentation describes the procedure or materials that should be used to construct the element. The *performance* presentation describes the end result of construction; the types of procedures and materials to achieve the end result are at the contractor's discretion. Only use one or the other form of presentation. When applicable, the performance presentation is preferred over the material or method presentation.
5. **Develop Outline.** The outline should cover the basic requirements of the work to be completed or the materials to be used. It should define the essential physical characteristics of the material or work (e.g., dimensional limitations, time, strength, weight, size, shape, configuration). Organize all relevant factors under each appropriate heading.
6. **Writing the Special Provision**. Once the outline has been developed and all research has been completed, the first draft can then be prepared. The design team may want to review existing Special Provisions for guidance. The following presents several grammatical recommendations for preparing Special Provisions:
   a. **Wording.** Write the Special Provision in the active voice (sentence begins with a verb) and the imperative mood (sentence expresses a command).

i. **Active Voice:** For example, "apply rubbed finish to the exposed surface."

ii. **Passive Voice:** For example, "rubbed finish shall be applied to the exposed surface."

b. **Sentences.** Prepare the Special Provision using simple language and words. Keep words and sentences short (20 words or less), unless complexity is unavoidable.

c. **Paragraphs.** Limit paragraphs to three to four sentences.

d. **Terminology.** Words should be used consistent with the bid items and their exact meaning. Use the same word throughout; do not use synonyms. Avoid any words that have a dual meaning. Section 14.2.4 presents the recommended terminology that should be used. Omit extraneous words and phrases.

e. **Will.** The term "will" is only used to describe actions to be performed by MDT.

f. **Pronouns.** Avoid the use of pronouns, even if this results in frequent repetition of nouns.

g. **Punctuation.** Carefully consider punctuation using the minimum number of punctuation marks consistent with the precise meaning of the language. Ensure that there can be no doubt on the meaning of any sentence.

h. **Parentheses.** Avoid the use of parentheses (). Instead, use commas or rewrite the sentence.

i. **Numbers.** It is usually unnecessary to write numbers both in words and figures. Write numbers less than or equal to ten as words. Write numbers higher than ten numerically. When writing dimensions, use fractions (e.g., ½", 1/8") and/or numerals (e.g., 0.20′, 10.00′, 1.7 gallons). Do not write 2" x 4"; instead, write 2" by 4". Times and dates should be written numerically. Decimals less than one should be proceeded by the zero, such as "0.02′".

7. **Reviewing.** Review previously completed paragraphs as succeeding ones take shape. Where necessary, redraft preceding paragraphs to reflect later thoughts.

   The design team should prepare and distribute the preliminary draft of the Special Provisions for review and comment at the Plan-in-Hand review. The design team will be responsible for incorporating the review comments into the final draft. The final draft will also be distributed for comment at the final plan review.

8. **Coordination.** The design team should coordinate with other units to ensure that Special Provisions are not duplicated (e.g., "Detour" or "Traffic Control and Sequence of Operations" written by both the Bridge Bureau and the Road Design Section). Where this occurs, combine the information into a single Special Provision that meets the needs of the project.

9. **Presentation.** Present Special Provisions as follows:
   a. Type Special Provisions specific to a project in MS-Word format. Type Standard Special Provisions that are modified in the Word format with the changes in bold type. When modifying a Standard Special Provision, other than addition to active field information, delete the revision date from the title.
   b. Identify Standard Special Provisions that are used without modification by their title and number. Identify only those Special Provisions that apply to road design items.

14.2.2 Format

Prepare Special Provisions in the active voice and in the same format as the *Standard Specifications*. The sections of the Special Provision that should be addressed include:

1. **Description.** Describe the work to be performed, with references to specifications, plans or other Special Provisions that further define the work. Where necessary or desirable for clarity, describe the relationship of this work item to other work items or other phases of construction.
2. **Materials and/or Equipment**. Designate the materials and/or equipment to be used in the work item and establish its requirements. Delineate complete specifications of the properties of each material and the method of tests. References may be made to American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), or other recognized specifications.
3. **Construction Details.** Describe the sequence of construction operations or the desired end product. Do not mix the two types of presentations as described in Section 14.2.1. Where practical, use the performance presentation. This will permit the contractor to use improved equipment, as well as new and advanced ideas in construction methods. Only use the presentation for the sequence of construction operations if it is critical to achieving the desired result. Specify quality control and quality assurance requirements, and specify who is responsible for testing.
4. **Method of Measurement.** Describe the components of the completed work item that will be measured for payment, the units of measurement and whether measured in original position, in transporting vehicles or in the completed work. Designate any modifying factors and other requirements needed to establish a definite, measured unit (e.g., disturbed or undisturbed, temperature, and waste).
5. **Basis of Payment.** Describe the units for which payment will be made, and define the scope of work covered by such payment. Ensure consistency with the bid items.

14.2.3 Guidelines

In addition to Sections 14.2.1 and 14.2.2, the following presents several guidelines the design team should consider when developing Special Provisions:

1. **Completeness.** When developing the Special Provision, ensure that the essentials have been included and that each requirement is definitive and complete. The Special Provision should not be vague.
2. **Consistency.** Ensure the Special Provision is consistent with other documents of the contract.
    a. Use consistent names for bid items when discussing materials. Do not use multiple terms to discuss one item.
    b. Refer to definitions and terms in the Standard Specifications to ensure consistent use of common terms.
3. **Clarity.** To ensure the Special Provision is clearly presented, review the following:
    a. Clearly delineate the method of measurement and payment.
    b. When referencing MDT in general, use Project Manager. When a specific point of contact is required, use the appropriate title or specific name and include contact phone number.
    c. Make a clear, concise analysis of the job requirements for general conditions, types of construction and quality of work. Do not leave the contractor in doubt on what will be required.
    d. Give directions, never suggestions.
    e. Never assume the Project Manager or contractor "knows" what is meant.
    f. Do not use phrases such as "as approved by the Project Manager," "at the discretion of the Project Manager," or "as directed by the Project Manager" in place of definite work requirements. Such phrases may lead to confusion or misunderstanding. Avoid conflicting or ambiguous requirements. Every specification should have only one meaning.
    g. Never conceal difficulties or hazards from the contractor.
4. **Conciseness.** Write each Special Provision as concise as practical. When reviewing the Special Provision, consider the following suggestions:
    a. Avoid duplications between the Special Provision and any related contract documents. When referencing Specifications, refer only to the appropriate Section number, do not identify the subsection.
    b. Do not give reasons for a Special Provision requirement.
    c. Do not provide additional information that is unnecessary for the preparation of bids and the accomplishment of the work.
    d. Once stated, do not repeat any instruction, requirement, direction or information given elsewhere in the contract documents.
    e. Do not include mandatory provisions that are required in general by the contract.

   f. Minimize the use of cross references.

5. **Correctness.** To ensure that the Special Provision is written correctly, review the following:
   a. Where practical, independently cross-check every factual statement.
   b. Do not include items that cannot be required or enforced.
   c. Ensure that the Special Provision does not punish the contractor or supplier.
   d. Ensure that the Special Provision does not unintentionally exclude an acceptable product, construction method or any equipment. If suppliers/products are specified in the provision, provide at least three suppliers/products and say "or approved equal". Listing one or two suppliers/products and adding "or approved equal" is not acceptable, however listing one or two specific products/suppliers may be used if appropriate and covered by an approved Public Interest Finding or Certification. When feasible, it is better to list specific material property requirements rather than identifying proprietary methods/materials that meet those requirements.
   e. Ensure that the provision does not change the basic design of the item.
   f. Do not specify impossibilities. The practical limits of workers and materials must be known and recognized.
   g. Specify standard sizes and patterns wherever practical.
   h. Avoid personal whims.
   i. Ensure that the contractor will not be held responsible for the possible inaccuracy of information furnished by MDT.
   j. Ensure that sufficient attention has been provided to assessing the durability or reliability of the material or procedure discussed. The use of permanent and recognized standards should be quoted to ensure that the specified performance or characteristics are achieved. If not, the testing criteria should be completely and accurately defined.
   k. Make a careful, critical examination of manufacturers' or trade associations' recommendations, and require supporting evidence before adopting them.
   l. Keep requirements stringent. A strong requirement can be relaxed more economically, when the need arises. Weak specifications cannot be strengthened without increasing cost and generating claims.
   m. Ensure that the provision gives directions that are consistent with the standard practice currently used by MDT.

14.2.4 Terminology

1. **Abbreviations.** Generally, avoid abbreviations. However, they may be used if they are defined and the definitions are consistent with the accepted meanings.
2. **Amount, quantity.** Use “amount” when writing about money only. When writing about measures of volume, such as cubic yards, use “quantity.”
3. **And/or.** Avoid using “and/or”; instead, use “and” alone, or “or” alone, or “or ... or both.” For example, “Unless otherwise specified by the plans or Special Provisions or both,…”.
4. **Any, all.** The word “any” implies a choice and may cause confusion. Use the term “all” in place of “any.” For example, “Correct all defects.”
5. **As per.** Do not use “as per”; instead, use “as stated,” “as shown,” “conforming to,” or other similar phrases.
6. **At the contractor's expense.** Do not use the phrase “at the contractor's expense”; instead use, “at no cost to the state” or “absorbed in the cost of other contract items.”
7. **Balance, remainder**. Use the term “balance” when referring to money. Use “remainder” to describe something or material left over.
8. **Coarse, course.** Use “coarse” to describe textures and “course” for layers.
9. **Conform**. Use the word “conform” to refer to dimensions, sizes, and fits that must be strictly adhered to (e.g., “cut bolt threads conforming to American Standards Association (ASA) Standards, Class 2 fit, coarse thread series”). Where a better product is acceptable, use the phrase “meeting the requirements of...” (e.g., aggregates meeting the specification requirements when tested in accordance with AASHTO T27.)
10. **Contractor.** Use the word “contractor” in place of the word “bidder” when writing Special Provisions for construction. Only use “bidder” for proposals.
11. **Or equivalent**. Use this phrase for only minor parts. The contractor may not know what is truly equivalent before awarded the contract. It is better to clearly specify those things that will be accepted as “equivalent.”
12. **Proposal.** Do not use the word “proposal” when the word “contract” is intended. Only use “proposal” to describe requirements during the bidding process.
13. **Resisting, resistant.** Do not use “corrosion-resisting,” but instead use, “corrosion-resistant.”
14. **Said.** Do not use “said pipe” or “said aggregates,” but instead use “this pipe” or “these aggregates.”
15. **Same.** Do not use “same” to replace a pronoun like “it” or “them” standing alone, such as “connected to same,” “specified for same,” “same will be given consideration,” “conforming to requirements for same.” Rewrite the sentence to clearly describe what is meant.

16. **Shall, will.** Do not use "shall." Use "will" to describe actions performed by MDT. Be careful with the use of "will" as action by MDT may be unintentionally implied.
17. **Such.** Do not end a sentence with the word "such." "Such" usually means "of this or that kind," or similar to something stated. Instead, either state that which is actually meant, name the work to be completed, or rephrase the sentence.
18. **Symbols.** Do not use the following symbols when writing Special Provisions:

Symbol	Write Instead
/	per, or "a"
X°	°F or degree Fahrenheit
%	percent
+	plus
–	minus
x	by

19. **The**. Do not eliminate "the" for brevity.
20. **Thoroughly**. Avoid using the adverb "thoroughly" (e.g., thoroughly wet, thoroughly dry, thoroughly clean) as it is unenforceable. Preferably, state the value of the intended requirements (e.g., in percent, in dimensions, or in number of passes).

MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Appendices

September 2016

MDT Road Design Manual

Appendices Introduction

The purpose of the *Road Design Manual (RDM)* is to provide uniform design practices for Montana Department of Transportation (MDT) design teams and consultant personnel preparing contract plans for projects involving MDT facilities. While the majority of the information can be found in the design manual chapters, additional design definitions, details, guidance, and example calculations are provided in the appendices for the design team to reference. The appendices are organized as follows:

- **Appendices A through J** consists of additional chapter content which includes supplemental design guidance, detailed equations and descriptions associated with various manual chapters.
- **Appendix K** consists of example calculations for the design team to reference during project computations. The examples are numbered based on the corresponding chapter content. For example, Example 2-1 corresponds to material in Chapter 2.

The following table summarizes the appendices and associated chapter references.

SUPPLEMENTAL CHAPTER CONTENT		
Appendix A	Definitions	All Chapters
Appendix B	Summary of Website Resources	All Chapters
Appendix C	Quality Assurance/Quality Control Guidance – *Reserved*	Chapter 1
Appendix D	MDT Internal Coordination - *Reserved*	Chapter 1
Appendix E	Level of Service Criteria	Chapter 2
Appendix F	Sight Distance • Sight Distance Overview • Stopping Sight Distance • Intersection Sight Distance • Passing Sight Distance • Decision Sight Distance	Chapter 2
Appendix G	Supplemental Horizontal Alignment Information • Superelevation Axis of Rotation • Rounding Curve and Alignment Data • Rounding of Stationing and Bearings • Compound Curve Applications	Chapter 3
Appendix H	Horizontal and Vertical Alignment Equations • Spiral Curves • Circular Curves • Compound Curves • Symmetrical Vertical Curves • Asymmetrical Vertical Curves	Chapters 3, 4
Appendix I	Cross Section Elements • Two-Way Left-Turn Lanes • On-Street Parking	Chapter 5
Appendix J	Supplemental Quantity Summaries Information • Quantity Rounding Criteria • Basis of Plan Quantities	Chapter 13

APPENDIX K: EXAMPLE CALCULATIONS	
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Roadside Safety • Example 9-1: Clear Zone for Both Sides of the Roadway • Example 9-2: Clear Zone for a Divided Highway • Example 9-3: Guardrail Length of Need for Obstacle Extending Beyond the Clear Zone • Example 9-4: Controlling Length of Need for Multiple Obstacles • Example 9-5: Minimum Length of Culvert	Chapter 9
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Appendix A

Definitions

Term	Definition	Relevant Chapter(s)
85th Percentile Speed	The speed at or below which 85-percent of vehicles travel on a given roadway.	2
Abandonment	The relinquishment of the public interest in right-of-way activity thereon with no intention to reclaim or use again for highway purposes.	6
Acceptable	Design criteria which do not meet desirable values, but yet is considered to be reasonable and safe for design purposes.	1
Access	A legal right to enter a highway facility from abutting property or public streets.	6
Access Control (Control of Access)	The condition in which the right of owners or occupants of abutting land or other persons to access, light, air or view in connection with a highway is fully or partially controlled by a public authority.	6
Accessible Route	A continuous, unobstructed path connecting all accessible elements following Americans with Disabilities Act (ADA) guidelines and spaces in a building, site or facility. A "site" is defined as a parcel of land bounded by a property line or a designated portion of a public right-of-way. A "facility" is defined as all or any portion of buildings, structures, site improvements, complexes, equipment, roads, walks, passageways, parking lots, or other real or personal property on a site.	6
Acquisition or Taking	The process of obtaining land and land interests.	6
Alignment Review	A meeting to determine and address the major project alignment challenges.	1
Alignment and Grade Review (AGR) Report	A report which provides written documentation of the horizontal and vertical alignment determinations made during the preliminary alignment review.	1

Allowable Headwater	The depth or elevation of the impoundment of cross-drainage flow above which damage or some other unfavorable result could occur.	11
Annual Average Daily Traffic (AADT)	The total yearly traffic volume in both directions of travel divided by the number of days in a year.	2
Approach	A road providing access from a public way to a highway, street, road, or to an abutting property.	6
Arterial	A roadway characterized by a capacity to move relatively large volumes of traffic while also serving adjacent properties.	2
Auxiliary Lane	The portion of the roadway adjoining the through traveled way for purposes supplementary to through traffic movement including parking, speed change, turning, storage for turning, weaving or truck climbing.	5
Auxiliary Through Lane	A through lane of limited length added upstream and downstream of an intersection.	6
Average Daily Traffic (ADT)	The total traffic volume in both directions of travel during a time period greater than one day but less than one year divided by the number of days in that time period.	2
Average Running Speed	The average speed of a vehicle over a specified section of highway. It is equal to the distance traveled divided by the running time (the time the vehicle is in motion). The average running speed is the distance summation for all vehicles divided by the running time summation for all vehicles.	2
Average Travel Speed	The distance summation for all vehicles divided by the total time summation for all vehicles, including stopped delays. (Note: Average running speed only includes the time the vehicle is in motion. Therefore, on uninterrupted flow facilities which are not congested, average running speed and average travel speed are equal.)	2
Award	The acceptance by MDT of a bid.	12
Axis of Rotation	The line about which the pavement is revolved to superelevate the roadway.	3
Backslope	The side slope created by the connection of the ditch bottom, upward and outward, to the natural ground (often referred to as the cut slope).	5
Barrier Curb	A longitudinal element, typically concrete, placed at the roadway edge for delineation, to control drainage, to control access, etc. Barrier curbs may range in height between 6” and 12” with a face steeper than 1 horizontal to 3 vertical. This term has been replaced in AASHTO with the term “vertical curb”.	5
Barrier Warrant	A criterion that identifies an area of concern which should be shielded by a traffic barrier, if judged to be practical.	9

Begin Curb Return	The point along the top back of curb where the curb return of an intersection meets the highway alignment (typical tangent portion).	6
Bicycle Boxes	Designated spaces at signalized intersections, placed between a set-back stop line and the crosswalk, that allow bicyclists to queue in front of motorized vehicles at traffic signals.	7
Bicycle Lane	A portion of a roadway which has been designated by striping, signing and pavement markings for the exclusive use of bicyclists.	7
Bicycle Path	A bikeway physically separated from motorized vehicular traffic by an open space or barrier.	7
Bikeway	Any road, path or way which in some manner is specifically designated as being open to bicycle travel, regardless of whether such facilities are designated for the exclusive use of bicycles or will be shared with other transportation modes.	7
Borrow	Material that has been dug from one location and will be used at another location.	4
Bridge	A structure, including supports, erected over a depression or obstruction, such as water, a highway, or a railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than approximately 20 feet between undercopings of abutments, between spring lines of arches, or between extreme ends of openings for multiple boxes; may include multiple pipes where the clear distance between openings is less than half of the smaller contiguous opening.	5, 11
Bridge Length	The length of a bridge structure is the overall length measured from centerline of bearing to centerline of bearing of the abutments.	5
Bridge Roadway Width	The clear width of the structure measured at right angles to the center of the roadway between the bottom of curbs or, if curbs are not used, between the inner faces of parapet or railing.	5
Bridge to Remain in Place	An "existing bridge to remain in place" refers to any bridge work which does not require the total replacement of both the substructure and superstructure.	5
Broken-Back Curves	Two closely spaced horizontal curves with deflections in the same direction and a short intervening tangent.	3
Buffer Area	The area between the roadway and the sidewalk that provides space between motorized vehicle traffic and non-motorized users (pedestrians and bicycles).	5

Buffered Bicycle Lane	An on-street lane that includes an additional striped buffer, typically 2 to 3 feet wide, between the bicycle lane and the motorized vehicle travel lane and/or between the bicycle lane and the motorized vehicle parking lane.	7
Bus	A heavy vehicle involved in the transport of passengers on a for-hire, charter or franchised transit basis.	4
CADD	Computer-aided drafting and design.	12
Capacity	The maximum number of vehicles which reasonably can be expected to traverse a point or uniform roadway section during a given time period under prevailing roadway, traffic, and control conditions.	2
Catch Basin	A structure with an opening for inletting drainage from a gutter or median and discharging the water through a conduit. In common usage it is a grated inlet with or without a sump.	11
Categorical Exclusion	A classification for projects that will not induce significant environmental impacts or foreseeable alterations in land use, planned growth, development patterns, traffic volumes, travel patterns, or natural or cultural resources.	1
Channel	The bed and banks that confine the surface flow of a natural or artificial stream. Braided streams have multiple subordinate channels, which are within the main stream channel.	11
Channelization	The directing of traffic through an intersection by the use of pavement markings (including striping, raised reflectors, etc.), medial separators or raised islands.	6
Circular Curves	Continuous arcs of constant radius which achieve the necessary highway deflection without an entering or exiting transition. Also known as simple curves.	3
Clear Zones	The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope and/or a recovery area. The desired width is dependent upon traffic volumes, speeds and roadside geometry.	9
Collector	A roadway characterized by a roughly even distribution of its access and mobility functions.	2
Comfort Criteria	Criteria which is based on the comfort effect of change in vertical direction in a sag vertical curve because of the combined gravitational and inertial forces.	6
Compound Curves	These are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other.	3

Construction Permit	Temporary legal access acquired by the State, outside the permanent right-of-way boundaries, to construct the highway project according to its proper design but on property which is not owned by the State.	12
Consultant	A firm or person hired by MDT to conduct special studies, design projects, and/or construction management.	1
Contractor	A company or firm hired by MDT to construct the project in the field according to the plans and specifications.	1
Controlling Criteria	A list of geometric criteria requiring approval if they are not met or exceeded.	2
Corner Island	A raised or painted island to channelize right-turn movements.	6
Cover	The extent of soil above the crown of a pipe or culvert (Chapter 11). Aggregate material used as a wearing/friction course with pavement seal application (Chapter 13).	11, 13
Crest Curve	Vertical curve that typically connects ascending grades that form a crest.	4
Criteria	A term typically used to apply to design values, usually with no suggestion on the criticality of the design value. Because of its basically neutral implication, the *RDM* frequently uses "criteria" to refer to the design values presented.	1
Critical Length of Grade	The maximum length of a specific upgrade on which a loaded truck can operate without experiencing a specified reduction in speed.	4
Critical Parallel Slope	Slopes which cannot be safely traversed by a run-off-the-road vehicle. Depending on the encroachment conditions, a vehicle on a critical slope may overturn. For most embankment heights, fill slopes steeper than 3:1 are considered critical.	9
Cross Drainage	The runoff from contributing drainage areas both inside and outside the highway right-of-way and the transmission thereof from the upstream side of the highway facility to the downstream side.	11
Cross Section	A vertical section of the ground and roadway at right angles to the centerline of the roadway, including all elements of a roadway.	3
Cross Slope	The slope in the cross section view of the travel lanes, expressed as a percent based on the change in vertical compared to the change in horizontal.	5
Cross Slope Rollover	The algebraic difference between the slope of the through lane and the slope of the adjacent pavement within the traveled way or gore.	3

Crossing Island	A pedestrian refuge in the median which provides an area in the middle of the road for pedestrians to stop if needed, when crossing the road in two stages (i.e., crossing one direction of vehicular travel at a time).	7
Crosswalk	The part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or, in the absence of curbs, from the edges of the traversable roadway. Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrians crossing by lines or other markings on the surface.	6
Culvert	A structure which is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity. A structure used to convey surface runoff through embankments. A structure, as distinguished from bridges, which is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert.	11
Curb Cut	Any opening in a curb where the full height curb section is terminated.	3
Curb Return	The circular segment of curb at an intersection which connects the tangent/edge of roadway (typically tangents) portions of the intersecting legs.	6
Curve to Spiral (CS)	A common point of the circular curve and the spiral of the far transition.	3
Cuts	Areas of highway cross sections located below natural ground elevation thereby requiring excavation of earthen material.	3
Decision Sight Distance	The distance required for a driver to detect information that is difficult to perceive, to recognize the condition or its potential threat, to select an appropriate speed and path, and to initiate and complete complex maneuvers.	2
Delay	The primary performance measure on interrupted flow facilities, especially at intersections. For intersections, average delay is measured and expressed in seconds per vehicle.	2
Density	The number of passenger car equivalents (PCE) occupying a given length of lane.	2
Department	Montana Department of Transportation.	1
Depressed Median	A median that is lower in elevation than the traveled way and designed to carry a certain portion of the roadway runoff.	5

Design Control	Attributes, values, or qualities that influence discrete geometric element dimensions or considerations.	2
Design Criteria	Dimensions and values that meet design control needs, such as curve radii, cross-sections, and merge lengths.	2
Design Discharge or Flow	The rate of flow for which a facility is designed.	11
Design Exception	The process of receiving approval from FHWA or MDT for using design elements which do not meet the criteria set forth in the *State Geometric Design Standards* as controlling criteria and identified in this *Manual* .	2
Design Flood Frequency	The recurrence interval of a flood event that is expected to be accommodated without exceeding the adopted design constraints. The return interval (recurrence interval or reciprocal of probability) used as a basis for the design discharge.	11
Design Hourly Volume (DHV)	The one-hour vehicular volume in both directions of travel in the design year selected for roadway design. The design hourly volume (DHV) is typically the 30th highest hourly volume during the design year.	2
Design Project Manager	The person who is responsible for the design of a project.	1
Design Speed	Speed selected to establish specific minimum boundaries for the geometric design elements for a particular section of highway.	2
Design Vehicle	The vehicle used to determine turning radii, off-tracking characteristics, pavement designs, etc., at intersections.	6
Desirable, Preferred	An indication that the design team should make every reasonable effort to meet the criteria and should only use a "lesser" design after due consideration of the "better" design.	1
Directional Design Hourly Volume (DDHV)	The highest of two directional volumes which combine to form the Design Hourly Volume (DHV).	2
Directional Distribution (D)	The distribution by percent of the traffic in each direction of travel during the peak or design hour.	2
Discharge	The rate of the volume of flow of a stream per unit of time, usually expressed in cubic yards per second.	11
Displaced Left-Turn Intersection (DLT)	An intersection that is also known as a continuous flow intersection (CFI) and a crossover displaced left-turn intersection. The displaced left turn (DLT) intersection displaces left-turn movements of an approach to an upstream signaized location, crossing traffic to the other side of the opposing traffic flow.	6

Diverging Diamond Interchange (DDI)	An interchange that is also known as the double crossover diamond and is an alternative to the conventional diamond interchange. The DDI includes directional crossovers on either side of the interchange that eliminates the need for left-turning vehicles to cross the path of approaching through vehicles.	6
Divided Highway	A highway with separated roadways for traffic moving in opposite directions.	2
Divided Roadway	A roadway with a median to separate opposing flows of traffic.	4
Dynamic Deflection	Amount of deformation experienced by a barrier when struck by a vehicle under testing conditions.	9
Edge of Travel Lane	The line between the portion of the roadway used for the movement of vehicles and the shoulder. The edge of travel lane is the center line, when considering opposing traffic.	9
Edge of Traveled Way	The line between the portion of the roadway used for the movement of vehicles and the shoulder regardless of the direction of travel.	9
Embankment	A bank of earth or stone built to prevent flooding or carry a roadway.	9
End Curb Return	The point along the minor roadway top back of curb where the curb return of an intersection meets the highway alignment (typically a tangent section).	6
Engineer's Estimate	MDT's cost estimate for construction of a project.	13
Environmental Assessment (EA)	A study to determine if the environmental impacts of a project are significant, thus requiring the preparation of an Environmental Impact Study (EIS).	1
Environmental Impact Statement (EIS)	A document which is prepared when it has been determined that a project will have a significant impact on the environment.	1
Equivalent Single-Axle Loads (ESALs)	The summation of equivalent 18,000 pound single-axle loads used to convert mixed traffic to design traffic for the design period.	2
Face of Curb	A distance of 6 inches from the back of curb.	5
Facility	All or any portion of buildings, structures, site improvements, complexes, equipment, roads, walks, passageways, parking lots, or other real or personal property on a site.	2
Farm Field Approaches	Revocable access points to the highway from agricultural land.	6
Federal Aid System	The routes within Montana which are eligible for the categorical Federal highway funds.	2
Fill Slopes	Slopes extending outward and downward from the hinge point to intersect the natural ground line.	5

Final Plan Review (FPR) Report	A report which provides written documentation of all decisions made during the Final Plan Review meeting.	
Finding of No Significant Impact (FONSI)	A result of an Environmental Assessment (EA) that shows a project will not cause a significant impact to the environment.	1
Floodplain	The alluvial land bordering a stream, formed by stream processes, that is subject to inundation by floods.	11
Flush Median	A paved median which is level with the surface of the adjacent roadway pavement.	5
Freeboard	The vertical distance between the level of the water surface, usually corresponding to design flow, and a point of interest such as a low chord of a bridge beam or specific location on the roadway grade.	11
Freeway	The highest level of arterial. This facility is characterized by full control of access, high design speeds, and a high level of driver comfort and safety.	2
Frontage Road	A road constructed adjacent and parallel to, but separated from, the highway for service to abutting property and for control of access.	2
Full Access Control	Access is allowed only at specified interchanges or at specified public approaches. It is intended to give high priority to the uninterrupted movement of through traffic. At-grade access is inconsistent with full access control.	2
Gore	The area downstream from the shoulder intersection points of an exit ramp (or upstream from that of an entrance ramp).	10
Gore Nose	The point where the pavement between the shoulders ends and the unpaved area begins as the ramp and mainline diverge from one another is the Gore Nose.	10
Grade Separation	A crossing of two highways, or a highway and a railroad, at different levels. This may also include a crossing of a bicycle/pedestrian facility and a roadway.	6
Gradient	The rate of slope between two adjacent vertical points of intersection (VPI) expressed as a percent. The numerical value for percent of grade is the vertical rise or fall in feet for each 100 feet of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).	4
Guideline	Indicating a design value which establishes an approximate threshold which should be met if considered practical.	1

Headwater (H_w)	That depth of water impounded upstream of a culvert due to the influence of the culvert construction, friction and configuration.	11
Heavy Vehicle	Any vehicle with more than four wheels touching the pavement during normal operation. Heavy vehicles collectively include trucks, recreational vehicles and buses.	2, 4
Heavy-Vehicle Adjustment Factor	A factor used in capacity analyses to determine the equivalent flow rate, expressed in terms of passenger cars per hour per lane, of heavy vehicles (i.e., trucks, buses and RVs) in the traffic stream.	2
High Speed	For geometric design purposes, high speed is defined as greater than 45 mph.	3
Highway, Street or Road	A general term denoting a public way for purposes of vehicular travel, including the entire area within the right of way. (Recommended usage: *in urban areas* - highway or street, *in rural areas* - highway or road).	2
Hinge Point (Freeways)	The point from which the fill height and depth of cut are determined. For fills, the point is located at the intersection of the inslope extension and the fill slope. For cuts, the hinge point is located at the toe of the backslope.	5
Hinge Point (Non-Freeways)	The point from which the fill height and depth of cut are determined. For fills, the point is located at the intersection of the subgrade cross slope and the fill slope for tangent sections and for the low side of superelevated sections. On the high side of superelevated sections, the point is located on the fill slope at a distance from the centerline equal to the distance from the centerline to the hinge point on the tangent section. For cuts, the hinge point is located at the toe of the backslope.	5
Horizontal Alignment	The route of the road defined by a series of horizontal tangents and curves.	3
Hydraulics	The characteristics of fluid mechanics involved with the flow of water in or through drainage facilities.	11
Hydrology	The study of the occurrence, circulation, distribution and properties of the waters of the earth and its atmosphere.	11
Ideal	Indicating a condition that may not exist in reality or be achievable under practical constraints but is regarded as perfect (e.g., traffic capacity under "ideal" conditions).	1
Impact Angle	For a longitudinal barrier, the angle between the face of the barrier and the vehicle's path at impact. For a impact attenuator, it is the angle between the axis of symmetry of the crash cushion and the vehicular path at impact.	9
Impact Attenuator (Crash Cushion)	A traffic barrier used to safely shield fixed objects or other obstacles of limited dimension from approximately head-on impacts by errant vehicles.	9

Improvement (with regard to right-of-way)	Any dwelling, out-building, other structure or fence, or part thereof, but not including public utilities, which lie within an area to be acquired for highway purposes.	1
Insignificant, Minor	Indicating that the consequences from a given action are relatively small and not an important factor in the decision-making for geometric design.	1
Inslope	The side slope in a cut section created by connecting the subgrade shoulder to the ditch bottom, downward and outward.	5
Intensity	The rate of rainfall upon a watershed, usually expressed in inches per hour.	11
Interchange	A system of ramps in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels.	6
Intersection	The general area where two or more highways join or cross, within which are included the roadway and roadside facilities for traffic movements in that area.	6
Intersection Angle	The angle between two intersecting roadways.	6
Intersection Sight Distance	The sight distance required within the corners of intersections to safely allow a variety of vehicular access or crossing maneuvers based on the type of traffic control at the intersection.	6
Intersection Traffic Control	The type of control (stop sign, signal, yield) provided at an intersection to allow multiple directions of traffic to take turns passing through the intersection.	6
Islands	Areas between traffic lanes used for controlling traffic movements.	6
Jacking and Boring	A type of horizontal auger earth boring. A type of culvert installation where an auger and hydraulic press is used to install the culvert without excavating.	11, 13
K-Values	The horizontal distance needed to produce a 1% change in vertical profile gradient.	4
Landing Area	The approach of a roadway leading into an intersection that stores stopped vehicles. A landing area may also apply to ramp design for pedestrian facilities.	6
L_c	Length of circular curve when spirals are used.	3
Length of Need	Total length of a longitudinal barrier, measured with respect to the centerline of roadway, needed to shield an area of concern. The length of need is measured to the last point of full-strength rail.	9
Letting (Bid Opening)	The time appointed for the opening of the proposals submitted by bidders.	12

Level of Service (LOS)	A qualitative concept which has been developed to characterize a traveler's perception of quality of service. In the *Highway Capacity Manual (HCM)* , the qualitative grades for each level of service (A through F) have been assigned to quantitative measures for each highway element.	2
Level Terrain	Relatively flat ground surface where the available stopping sight distances are generally long or can be made to be so without construction difficulty or major expense.	2
Limited Access Control	Access is allowed at specified public roads or at private driveways as specified in legal agreements and/or deeds. The established street system is given first priority in access to the highway. When it is determined that reasonable private access cannot be provided using the public access, direct private access may be allowed at specific points.	2
Limited Access Highway (or Facility)	A portion of roadway with limited access control imposed by the governing public authority.	2
Local Road	All public roads and streets not classified as freeways, arterials, or collectors are classified as local roads and streets. Local roads and streets are characterized by their many points of direct access to adjacent properties and their relatively minor value in accommodating mobility.	2
Low Speed	For geometric design purposes, low speed is defined as 45 mph or less.	3
Low Speed Urban Streets	All streets within urbanized and small urban areas with a design speed of 45 mph or less.	3
L_s	Length of spiral.	3
Major Collector	A roadway that serves traffic generators that are not served by the higher arterial system. This could include schools, freight distribution areas, parks or other agricultural areas. Major collectors link these types of areas to routes of higher classification, such as arterials.	2
Maximum Superelevation (e_{max})	The overall superelevation control used on a specific facility. Its selection depends on several factors including overall climatic conditions, terrain conditions, type of facility and type of area (rural or urban).	3
May, Could, Can, Suggest, Consider	A permissive condition. The design team is allowed to apply individual judgment and discretion to the criteria when presented in this context. The decision will be based on a case-by-case assessment.	1
MDT Detailed Drawings	Drawings approved for repetitive use, showing details to be used where appropriate.	12
Median	The portion of a divided highway separating the two traveled ways for traffic in opposite directions. The median width includes both inside shoulders.	5

Median Barrier	A longitudinal barrier used to prevent an errant vehicle from crossing the median of a divided highway. This prevents crashes between traffic traveling in opposite directions.	9
Median Crossover	Temporary segments of roadway that transfer one or more lanes of traffic across a median away from an adjacent construction zone segment.	10
Median Opening	Openings in the median (raised or depressed) on divided facilities which allow vehicles to cross the facility or to make a U-turn.	6
Median Separator	Channelization which separates opposing traffic flows, alerts the driver to the cross road ahead and regulates traffic through the intersection.	5
Median Slope	The slope in the cross section view of a depressed median beyond the surfacing inslope, expressed as a ratio of the change in horizontal to the change in vertical.	5
Median U-Turn (MUT) Intersection	An intersection that is also known as the Median U-Turn Crossover, and sometimes referred to as a boulevard turnaround, a Michigan loon, or a ThrU-Turn Intersection. The MUT intersection replaces direct left-turns at an intersection with indirect left-turns using a U-turn movement in a wide median.	6
Minimum, Maximum, Lower, Upper (Limits)	Representative of generally accepted limits within the design community but not necessarily suggesting that these limits are inflexible.	1
Minor Arterial	In rural areas, minor arterials will provide a mix of interstate and interregional travel service. In urban areas, minor arterials may carry local bus routes and provide intra-community connections. When compared to the principal arterial system, the minor arterials accommodate shorter trip lengths and lower traffic volumes, while providing more access to property.	2
Minor Collector	A roadway that provides links to local traffic generators within rural and urban areas. These types of routes may be spaced consistently to accumulate traffic from local roads and bring developed areas to other collector roadways.	2
Mountable Curb	A longitudinal element, typically concrete, placed at the roadway edge for delineation, to control drainage, to control access, etc. Mountable curbs typically have a height of 6″ or less with a face no steeper than 1 horizontal to 3 vertical. This term has been replaced in AASHTO with the term “sloped curb”.	5

Mountainous Terrain	Steep ground surface where longitudinal and transverse changes in elevation are abrupt and extensive grading is frequently needed to obtain acceptable alignments.	2
National Highway System	A system of highways determined to have the greatest national importance to transportation, commerce and defense in the United States.	2
National Network for Trucks	In Montana, the Interstate highway system and all primary routes that existed prior to the Intermodal Surface Transportation Efficiency Act (ISTEA).	2
New Construction	Horizontal and vertical alignment on a new location.	2
No Control Intersection	An intersection where none of the legs are controlled by a traffic control device.	6
Non-Accessible Route	Any pedestrian facility which contains features that make it impractical to meet all of the criteria for accessible routes, following Americans with Disabilities Act (ADA) guidelines.	6
Non-Recoverable Parallel Slope	Slopes which can be safely traversed but upon which an errant motorist is unlikely to recover. The run-off-the-road vehicle will likely continue down the slope and reach its toe. For most embankment heights, if a fill slope is between 3:1 (inclusive) and 4:1 (exclusive), it is considered a non-recoverable parallel slope.	9
Normal Crown	The typical cross section on a tangent section referenced to centerline with downslope to the edge of pavement.	3
Notice to Proceed	Written notice given to the contractor to begin the contract work.	12
One-Way Separated Bicycle Lane	A facility that is also known as a cycle track or protected bicycle lane, is a bicycle facility within the street right-of-way separated from motorized vehicle traffic by a buffer and/or a physical barrier.	7
Operating Speed	The speed at which drivers are observed operating their vehicles during free-flow conditions.	2
Overpass	A grade separation where the subject highway passes over an intersecting highway or railroad.	6
Pace	The 10 miles per hour (mph) range of speeds in which the highest number of speed observations are recorded.	2
Painted Nose	This is the point (without width) where the pavement striping on the left side of the ramp converges with the stripe on the right side of the mainline traveled way.	6
Parallel Slopes	Cut and fill slopes for which the toe runs approximately parallel to the flow of traffic.	9
Parking Lane	An additional lane for the parking of vehicles.	6
Passing Lane	An auxiliary lane added to two-lane facilities to allow vehicles to pass. For multilane facilities, the inside lane is sometimes referred to as a passing lane.	5

Passing Sight Distance	Passing sight distance considerations are limited to two-lane, two-way highways. On these facilities, vehicles may overtake slower moving vehicles, and the passing maneuver must be accomplished on a lane used by opposing traffic.	2
Pavement Preservation	A type of preventative maintenance that includes such treatments as crack seal, seal and cover, milling less than or equal to 0.2 feet, and overlays less than or equal to 0.2 feet (the overlay thickness can be increased to a total of 0.22 feet, if an isolation lift is needed to address heavy crack sealing of the existing surfacing).	2
PC	Point of curvature (beginning of curve).	3
PCC	Point of compound curvature.	3
Peak Discharge	The highest value of discharge attained by a flood. The maximum discharge rate on a runoff hydrograph for a given flood event.	11
Peak Hour Factor (PHF)	A ratio of the volume occurring during the peak hour to the peak rate of flow during a given time period within the peak hour (typically, 15 minutes).	2
Pedestrian Hybrid Beacon	A pedestrian/bicyclist activated signal that rests in dark when not in use. It begins with a yellow light flashing that turns solid to alert drivers to slow, and then displays a solid red light requiring drivers to remain stopped while pedestrians and bicyclists receive a walk indication. The beacon then changes to alternating flashing red lights while pedestrians and bicyclists receive a flashing don't walk indication to signal that motorists may proceed after pedestrians and bicyclists are no longer in conflict.	7
Pedestrian Path	A hard-surface path adjacent to the roadway in lieu of a sidewalk in areas where other bicycle facilities exist or where bicyclists typically share the road on a low-volume facility.	7
Performance Curves	A set of curves which illustrate the effect grades will have on the design vehicle's acceleration and/or deceleration.	4
Permanent Right-of-Way	Highway right-of-way acquired for permanent ownership (fee simple title) by the State for activities which are the responsibility of the State for an indefinite period of time. The State obtains fee title to the property.	12
Physical Nose	The point where the ramp and mainline shoulders converge.	6
PI	Point of intersection of tangents.	3
Plan-in-Hand (PIH) Report	A report which provides written documentation of all decisions made during the Plan-In-Hand office and field review meetings.	1

Plan-in-Hand (PIH) Review	An in-depth office and on-site review of all project elements to ensure that major details have been satisfactorily incorporated into the construction plans, and to define the limits of construction for use in permitting, Right-of-Way acquisition, and utility relocation.	1
Plans	The contract drawings which show the location, character and dimensions of the prescribed work, including layouts, profiles, cross sections and other details.	1
Policy	A MDT practice which MDT generally expects the design team to follow, unless otherwise justified.	1
Positive Protection	Devices that contain and/or direct vehicles and prevent intrusion into the work area.	10
Possible	Indicating that which can be accomplished. Because of its rather restrictive implication, this word will not be used in the *RDM* for the application of geometric design criteria.	1
Posted Speed Limit	The regulatory speed limit on a highway.	2
Practical, Feasible, Reasonable	Advising the design team that the decision to apply the design criteria should be based on a subjective analysis of the anticipated benefits and costs associated with the impacts of the decision. No formal analysis (e.g., cost-effectiveness analysis) is intended, unless otherwise stated.	1
PRC	Point of reverse curvature.	3
Preliminary Field Review (PFR)	An initial field review meeting held after a project has been nominated to determine the major design features, and to discuss other project-related issues and any potential problems.	1
Preliminary Field Review (PFR) Report	A report which provides written documentation of all major determinations made during the Preliminary Field Review meeting.	1
Primary System	A system of routes that includes Non-National Highway System (NHS) rural minor arterials.	2
Principal Arterial	In both rural and urban areas, the principal arterials serve the highest traffic volumes and the greatest trip lengths. These facilities may be two or more lanes in each direction, with or without a median. In some cases, the level of geometric design is equivalent to that of freeways.	2
Private Access Control	The condition where the public authority fully or partially controls the right of abutting owners to have access to and from the public roadway.	2
Private Approach	An approach which allows access to and/or from private property (e.g., commercial, industrial and residential).	2
Profile Grade Line	A series of tangent lines connected by vertical curves. It is typically placed along the roadway centerline of undivided facilities and at the edges of the two roadways on the median side on divided facilities.	4

Project	An undertaking by MDT for highway construction, including preliminary engineering, acquisition of right-of-way and actual construction, or for highway planning and research, or for any other work or activity to carry out the provisions of the law for the administration of highways.	1
Project Scope of Work	The basic intent of the highway project which determines the overall level of highway improvement.	1
Proposal	The written offer of the bidder to perform the work described in the plans and specifications, and to furnish the labor and materials at the prices quoted by the bidder.	1
PT	Point of tangency (end of curve).	3
Public Approach	A connection to and/or from a street, road, alley or other public roadway to a highway facility.	2
Public Hearing/Meeting	A meeting conducted by MDT to inform the general public on MDT's proposed plan of action or design proposal.	2
Public Information	The communication strategies that seek to inform affected roadway users, the general public, area residences and businesses, as well as appropriate public entities about the project, the expected construction zone impacts, and the changing conditions of the project.	10
Quantity Summaries	A listing of the project construction quantities which are used by both MDT and the contractor for determining the project construction costs.	13
Raised Median	A median which contains a raised portion or island within its limits.	5
Ramp	A short roadway connecting two or more legs of an interchange or connecting a frontage road and main lane of a highway.	6
Ramp Terminal Intersections	An intersection between a cross road and the on- or off-ramp from a freeway.	6
Rate of Flow	The equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway on which the volume is collected over a time interval less than one hour.	2
Reconstruction	Work which includes one or more of the following: a) Full-depth pavement reconstruction for more than 50-percent of the project length; b) Intermittent reconstruction of the existing horizontal and vertical alignment for more than 25-percent of the project length; and/or c) Addition or removal of through travel lanes.	2
Recoverable Parallel Slope	Slopes which can be safely traversed and upon which an errant motorist has a reasonable opportunity to stop and return to the roadway. Fill slopes 4:1 and flatter are considered recoverable.	9

Recreational Vehicle	A heavy vehicle, generally operated by a private motorist, engaged in the transportation of recreational equipment or facilities; examples include campers, boat trailers, motorcycle trailers, etc.	4
Rectangular Rapid-Flashing Beacon	A pedestrian-actuated set of amber light-emitting diodes (LEDs) that rapidly flash when actuated.	7
Regulated Access	Means of limiting access to/from private property and the highway right-of-way by the use of revocable approach permits.	2
Rehabilitation	Work primarily intended to extend the service life of the existing roadway by making cost-effective improvements to upgrade the roadway. It may include full-depth pavement reconstruction for up to 50-percent of the project length and may include horizontal and vertical alignment revisions for up to 25-percent of the project length.	2
Relative Longitudinal Slope	The difference between the centerline grade and the grade of the edge of traveled way.	3
Restricted Crossing U-Turn (RCUT) Intersection	An intersection that is also known as a superstreet intersection, a J-turn intersection, or a synchronized street intersection. The RCUT intersection replaces direct left-turns and through movements from cross street approaches at an intersection with indirect left-turns using a U-turn movement in a wide median.	6
Reverse Crown	A superelevated roadway section which is sloped across the entire traveled way in the same direction and at a rate equal to the cross slope on a tangent section.	3
Reverse Curves	Two simple curves with deflections in opposite directions which are joined by a common point or a relatively short tangent distance.	3
Right-of-Way	A general term denoting land, property or interest therein, usually a strip acquired for or devoted to a highway use.	1
Right-of-Way Appraisal	A determination of the market value of property including damages, if any, as of a specified date, resulting from an analysis of facts.	1
Right-of-Way Easements	A right for a specific purpose acquired by the State for the limited usage of property not owned by the State. Types of right-of-way easements may include maintenance easements, utility easements, storm sewer easements and roadway easements.	12
Right-of-Way Estimate	An approximation of the market value of property including damages, if any, in advance of an appraisal.	1
Roadside	A general term denoting the area adjoining the outer edge of the roadway.	1

Roadside Barrier	A longitudinal barrier used to shield obstacles located within an established clear zone. Roadside barriers include guardrail, concrete barrier rails, etc.	9
Roadside Obstacles	A general term to describe roadside features which cannot be safely impacted by a run-off-the-road vehicle. Roadside obstacles include both fixed objects and non-traversable roadside features (e.g., rivers).	9
Roadway	The portion of a highway including shoulders, for vehicular use. A divided highway has two or more roadways. During construction, the roadway is the portion of a highway within the limits of construction.	1
Roadway Section	The combination of the traveled way, both shoulders and any auxiliary lanes on the highway mainline.	5
Rock Cut	A roadway cut excavated through rock.	13
Roller Coaster	A type of profile that may be an outcome of fitting an alignment across varying topography; however the design team should avoid excessive ups and downs, which may be unpleasant aesthetically and difficult for drivers to navigate.	4
Rolling Terrain	Ground surface where the natural slopes consistently fall below and rise above the roadway and occasional steep slopes offer some restriction to horizontal and vertical alignment.	2
Roundabout	A form of yield-controlled intersection with a generally circular shape, characterized by yield on entry and circulation around a central island.	6
Rumble Strips	A series of grooves cut into the pavement or a series of raised strips along the centerline or shoulder or the roadway which change the noise a vehicle's tires make on the surface and create vibrations that warn drivers of speed restrictions or the edge of the lane.	5
Running Speed	The moving speed of a vehicle traversing a specified section of highway. It is equal to the distance traveled divided by the running time (the time the vehicle is in motion).	2
Rural Area	Those places outside the boundaries of urban areas.	2
Sag Curve	Vertical curve that typically connects descending grades forming a sag.	4
Scope of Work (SOW) Report	A report that identifies the proposed design elements and major design features of the subject project, provides an overview of the project improvements and lists all approved design exceptions.	1
Secondary System	A system of routes that includes Non-National Highway System (NHS) rural major collectors.	2

Service Flow Rate	The maximum hourly vehicular volume which can pass through a highway element at the selected level of service.	2
Shall, Require, Will, Must	A mandatory condition. The design team is obligated to adhere to the criteria and applications presented in this context or to perform the evaluation indicated. For the application of geometric design criteria, the *RDM* limits the use of these words.	1
Shared Facility	A facility along a roadway that can serve both pedestrians and bicyclists.	7
Shared Roadway	A roadway which is open to both bicycle and motor vehicle travel.	7
Shelf	On curbed urban facilities without sidewalks, the relatively flat area (2% slope) located between the back of the curb and the break for the fill slope or backslope.	5
Should, Recommend	An advisory condition. The design team is strongly encouraged to follow the criteria and guidance presented in this context, unless there is reasonable justification not to do so.	1
Shoulder	The portion of the roadway contiguous to the traveled way for lateral support of base and surface courses, improved roadway operation, increased clear recovery area, space for emergency stops, and for other purposes. On sections with curb and gutter, the shoulder extends to the face of the curb.	5
Shoulder Slope	The slope in the cross section view of the shoulders, expressed as a percent.	5
Shoulder Width	The width of the shoulder measured from the edge of the traveled way to the intersection of the shoulder slope and surfacing inslope planes. On curb and gutter sections, the width of the shoulder is measured from the edge of the traveled way to a point 0.5 feet in front of the back of curb.	5
Shy Distance	Distance from the edge of the traveled way beyond which a roadside object will not be perceived as an immediate hazard by the typical driver to the extent that it will change vehicular placement or speed.	9
Side Friction Factor (f)	A numerical factor which represents the vehicle's need for side friction between the vehicle's tires and the pavement surface. It also represents the lateral acceleration that acts on a vehicle.	3
Side Slope	Both fill slopes and cut slopes used to conform to existing conditions along the roadside.	5
Sidewalk	A dedicated pedestrian facility adjacent to the roadway and separated from vehicular traffic by a curb (e.g., curb-tight sidewalk) or buffer area (detached sidewalk).	5, 7

Signalized Intersection	An intersection which is controlled by a traffic signal. The operations of a signalized intersection are impacted by the signal phasing and timing of the intersection.	6
Significant, Major	Indicating that the consequences from a given action are obvious to most observers and, in many cases, can be readily measured.	1
Site	A parcel of land bounded by a property line or a designated portion of a public right-of-way.	1
Slope Offset	On curbed facilities with sidewalks, the area between the back of the sidewalk and the break for the fill slope or backslope.	5
Small Urban Area	Those areas with a population greater than 5,000 and not within any Urbanized Areas.	2
Special Provisions	Additions and revisions to the Standard and Supplemental Specifications applicable to an individual project.	14
Specifications	The compilation of provisions and requirements for the performance of prescribed work.	14
Speed Reduction Treatment	A roadway treatment designed to reduce vehicle speeds.	6
Spiral Curves	Curvature arrangements used to transition between a tangent section and a circular curve, which are consistent with the transitional characteristics of vehicular turning paths. When moving from the tangent to the circular curve, the sharpness of the spiral curve gradually increases from a radius of infinity to the radius of the circular curve.	3
Spiral to Curve (SC)	A common point of the spiral and the circular curve of the near transition.	3
Spiral to Tangent (ST)	A common point of the spiral and the tangent of the far transition.	3
Spline Curve	A curve drawn using a flexible template to meet field conditions.	4
Spline Grade	A grade developed using a flexible template to meet field conditions.	4
Standard	A design value which cannot be changed without formal documentation, such as a design exception.	2
Standard Bicycle Lane	An on-street facility that provides space designated for bicyclists, separated from vehicles by pavement markings.	7
Standard Specifications	*Standard Specifications for Road and Bridge Construction.* A book of specifications approved for general application and repetitive use.	14
State Highway	Any public highway planned, laid out, altered, constructed, reconstructed, improved, repaired, maintained or abandoned by the Montana Department of Transportation.	2

State Maintenance System	Public highways designated by the Transportation Commission that are to be maintained by the State. This system must include all the highways that the Department maintained on July 1, 1976.	2
Stationing	A system of measurement used for road layout and construction.	3
Stop Controlled Intersection	An intersection where one or more legs are controlled by a stop sign.	6
Stopping Sight Distance	The sum of the distance traveled during a driver's perception/reaction or brake reaction time and the distance traveled while braking to a stop.	2
Storm Drain Inlet	A structure for capturing concentrated surface flow. May be located along the roadway, in a gutter, in the highway median, in a roadside ditch or in a field.	11
Superelevation	The amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.	3
Superelevation Rollover	The algebraic difference (A) between the superelevated traveled way cross slope and shoulder slope on the outside of a horizontal curve.	3
Superelevation Runoff (L)	The distance needed to change the cross slope from the end of the tangent runout (adverse crown removed) to a section that is sloped at the design superelevation.	3
Superelevation Transition Length	The distance required to transition the roadway from a normal crown section to full superelevation. Superelevation transition length is the sum of the tangent runout (TR) and superelevation runoff (L) distances.	3
Supplemental Specifications	Approved conditions and revisions to the Standard Specifications.	14
Surface Transportation Program	Refers to all Non-NHS routes and is a block-grant program which provides Federal-aid funds for any public road not functionally classified as a minor rural collector, or a local road or street.	2
Surfacing Inslope	The slope extending from the edge of shoulder to the subgrade shoulder point, expressed as a ratio of the change in horizontal to the change in vertical.	5
Symmetrical Vertical Curve	A vertical curve where the horizontal distance from the VPC to the VPI equals the horizontal distance from the VPI to the VPT.	4
Tangent Runout (TR)	The distance needed to transition the roadway from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., the outside lane(s) is level).	3
Tangent to Spiral (TS)	A common point of the spiral and the tangent of the near transition.	3

Target	Selected criteria that the design team is striving to achieve. However, not meeting these criteria will typically not require a justification.	1
Temporary Easement	Property acquired for the legal right of usage by MDT to serve a specific purpose for a limited period of time (e.g., maintenance and protection of traffic during construction). Once the activity is completed, MDT yields its legal right of usage and returns the land to its original condition as close as practical.	12
Temporary Roadway	A road that is designed and built along a temporary alignment solely for use during construction.	10
Time of Concentration (T_c)	The time it takes water from the most distant point (hydraulically) to reach a watershed outlet. T_c varies, but it is often used as a constant.	11
Toe of Slope	The intersection of the fill slope with the natural ground or the inslope with the ditch bottom.	5
Top of (Cut) Slope	The intersection of the backslope with the natural ground.	5
Traffic Calming Measures	Physical designs or other measures put in place on roadways for the intention of slowing down or reducing motor-vehicle traffic as well as improving safety for pedestrians and bicycles.	8
Traffic Control Plan	Describes measures within the contract to facilitate roadway users through a construction zone, work zone, or an incident area, and addresses traffic safety and control through the construction and work zone.	10
Transition Length	The distance required to transition the roadway from a normal crown (*NC*) section to a full superelevation. Superelevation transition length is the sum of the tangent runout (*TR*) and superelevation runoff (*L*) distances.	3
Transitional Area	Those areas providing connections between urban and rural areas.	2
Transportation Management Plan	A plan established to clearly direct and control traffic disruptions that call for coordinated actions from several services responsible for road management on a given roadway network.	10
Transportation Operations	Operations used to mitigate impacts of the construction zone on the operation and management of the transportation system within the construction zone impact area.	10
Transverse Slopes	Cut and fill slopes for which the toe runs approximately perpendicular to the flow of traffic. Transverse slopes are typically formed by intersections between the mainline and approach, median crossovers or side roads.	9
Travel/Traffic Lane	The portion of the traveled way for the movement of a single line of vehicles.	5

Traveled Way	The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.	5
Traversable Slopes	A slope or cross section in which a vehicle can safely cross. Parallel slopes 3:1 or flatter are considered traversable.	9
Truck	A heavy vehicle engaged primarily in the transport of goods and materials, or in the delivery of services other than public transportation. For geometric design and capacity analyses, trucks are defined as vehicles with six or more tires. Data on trucks are compiled and reported by the Transportation Planning Division.	4
Truck Factor (T)	A factor which reflects the percentage of heavy vehicles (trucks, buses and recreational vehicles) in the traffic stream during the DHV, ADT and/or AADT. For geometric design and capacity analysis, trucks are defined as vehicles with six or more tires.	2
Turn Lane	An auxiliary lane adjoining the through traveled way for speed change, storage and turning.	6
Turning Roadway	A channelized roadway (generally separated by a raised island or depressed gor area) connecting two legs of an intersection.	6
Turning Template	A graphic representation of a design vehicle's turning path depicting various angles of turns for use in determining acceptable turning radii designs.	6
Two-Stage Left-Turn Box	A designated area of an intersection that allows bicyclists to safely and comfortably make left-turns at multilane intersections from a right-side bicycle lane or cycle track.	7
Two-Way Left-Turn Lane (TWLTL)	A lane configuration that provides a center lane exclusively for left-turning vehicles from either direction.	5
Two-Way Separated Bicycle Lane	A facility, also known as a two-way cycle track or two-way protected bicycle lane, within the street right-of-way separated from motorized vehicle traffic by a buffer and a physical barrier.	7
Typical	Indicating a design practice that is most often used in application. However, this practice does not necessarily represent the "best" treatment at a given site.	1
Underpass	A grade separation where the subject highway passes under an intersecting highway or railroad.	6
Undivided Roadway	A roadway with one or multiple lanes in each direction arranged within a single roadway with no median to separate opposing flows of traffic.	4
Unsymmetrical Vertical Curve	A vertical curve where the horizontal distance from the Vertical Point of Curvature (VPC) to the Vertical Point of Intersection (VPI) is not equal to the horizontal distance from the VPI to the Vertical Point of Tangency (VPT).	4

Urban Area	Those places within boundaries set by the responsible State and local officials or a place that has urbanized characteristics.	2
Urban System	A system that includes both minor arterials and major collectors within urban boundaries.	2
Urbanized Area	Those areas with a population greater than 50,000, as designated by the Bureau of the Census.	2
Utility Occupancy Area	A strip of right-of-way reserved for the placement of utilities.	9
Vertical Clearance	A vertical dimension which must be clear of obstructions to allow vehicles to pass.	4
Vertical Alignment	The vertical aspect of the road, including crest and sag curves and the straight grade lines connecting them.	3
Vertical Point of Curvature (VPC)	The point at which a tangent grade ends and the vertical curve begins.	4
Vertical Point of Intersection (VPI)	The point where the extension of two tangent grades intersect.	4
Vertical Point of Tangency (VPT)	The point at which the vertical curve ends and the tangent grade begins.	4
Yield Control Intersection	An intersection where one or more legs are controlled by a yield sign and are permitted to enter the intersection without stopping if there are no potentially conflicting vehicles on the major roadway.	6

Appendix B

Summary of Website Resources

Appendix B summarizes all of the website resources that are shown as hyperlinks within the respective chapters in the Montana Department of Transportation (MDT) Road Design Manual (RDM). Below is a table that provides the full website information for the design team to access, as needed.

Agency/Document	Website Link
General	
MDT Road Design Manual, 2016	http://www.mdt.mt.gov/publications/manuals.shtml
Chapter 1 – Road Design Guidelines and Procedures	
MDT Organizational Chart	http://www.mdt.mt.gov/other/webdata/external/dir/orgchart.pdf
MDT EPS Design Team Activities (consultant projects)	http://www.mdt.mt.gov/other/webdata/external/cdb/ACTIVITY_DESCRIPTIONS/CONSULTANT_DESIGN_2500_MU.PDF
MDT Project Work Type Codes	http://www.mdt.mt.gov/other/webdata/external/EISS/Work_Type_Codes/Workcodes.PDF
MDT Project Work Type Definitions	http://www.mdt.mt.gov/other/webdata/external/EISS/Work_Type_Codes/Definitions.PDF
MDT Cost Estimating Information	http://www.mdt.mt.gov/business/contracting/cost.shtml
MDT Project Reports	http://www.mdt.mt.gov/publications/forms.shtml
MDT Publications	http://www.mdt.mt.gov/publications/manuals.shtml
MDT Design Memoranda	http://www.mdt.mt.gov/business/consulting/design_memos.shtml

Chapter 2 – Basic Design Controls	
MDT Functional Classification Map	http://mdt.maps.arcgis.com/home/webmap/viewer.html?webmap=3fe8695311b04116bdbbb776d44dd96b
MDT National Highway System Map	http://mdt.maps.arcgis.com/home/webmap/viewer.html?webmap=1eab4f286f61456b87fa28dc42e49e8f
Federal Highway Administration (FHWA), MDT Guidelines for Nomination and Development of Pavement Projects	In-Progress.
Department of Justice/Department of Transportation Joint Technical Assistance on the Title II of the Americans with Disabilities Act (ADA) Requirements to Provide Curb Ramps when Streets, Roads, or Highways are Altered through Resurfacing	http://www.fhwa.dot.gov/civilrights/programs/doj_fhwa_ta.cfm
MDT Route Segment Plan Map	http://www.mdt.mt.gov/other/webdata/external/cadd/MONTANA_ROAD_DESIGN_MANUAL/ROUTE_SEGMENT_PLAN_2014_.PDF
MDT Roadway Width Decision Process	In-Progress.
MDT Bridge Design Standards	http://www.mdt.mt.gov/other/webdata/external/bridge/design-stds-manual/design_stds_manual.pdf
MDT Approach Manual for Landowners and Developers	http://www.mdt.mt.gov/publications/docs/manuals/approach_manual.pdf
MDT Design Exception Template	http://www.mdt.mt.gov/publications/forms.shtml
Chapter 5 – Cross Section Elements	
MDT Route Segment Plan	http://www.mdt.mt.gov/other/webdata/external/cadd/MONTANA_ROAD_DESIGN_MANUAL/ROUTE_SEGMENT_PLAN_2014_.PDF
MDT Pavement Design Manual	http://www.mdt.mt.gov/other/webdata/external/pavementanalysis/pavementdesignmanual.pdf
MDT Rumble Strip Guidance	http://www.mdt.mt.gov/other/webdata/external/cadd/design_memos/2015-07-08_RUMBLE_STRIP-4.pdf
Chapter 6 – Intersections and Interchanges	
MDT Approach Manual for Landowners and Developers	http://www.mdt.mt.gov/publications/docs/manuals/approach_manual.pdf
Chapter 8 – Urban Design Considerations	
MDT Approach Manual for Landowners and Developers	http://www.mdt.mt.gov/publications/docs/manuals/approach_manual.pdf
ITE Traffic Calming Measures	http://www.ite.org/traffic/tcdevices.asp
Chapter 9 – Roadside Safety	
MDT Detailed Drawings	http://www.mdt.mt.gov/business/contracting/detailed_drawings.shtml
MDT Rumble Strip Guidance	http://www.mdt.mt.gov/other/webdata/external/cadd/design_memos/2015-07-08_RUMBLE_STRIP-4.pdf

Chapter 10 – Work Zone Traffic Control	
MDT Work Zone Safety and Mobility	http://www.mdt.mt.gov/other/webdata/external/cadd/wzsm/WZSM_GUIDANCE.pdf
MDT Project Report Templates	http://www.mdt.mt.gov/publications/forms.shtml
Chapter 11 – Drainage and Irrigation Design	
MDT Hydraulics Manual	http://www.mdt.mt.gov/publications/manuals.shtml
MDT Permanent Erosion and Sediment Control Design Guidelines	http://www.mdt.mt.gov/publications/docs/manuals/pesc_manual.pdf
MDT Detailed Drawings	http://www.mdt.mt.gov/business/contracting/detailed_drawings.shtml
Chapter 12 – Plan Preparation	
MDT Sample Plans	http://www.mdt.mt.gov/other/webdata/external/cadd/montana_road_design_manual/rmanrdpree01.pdf
MDT Computer-Aided Design & Drafting (CADD) Standards	http://www.mdt.mt.gov/business/contracting/cadd.shtml
MDT Sample Alignment and Grade Review (AGR) Plans	In-Progress.
Chapter 13 – Quantity Summaries	
MDT Item Codes	http://www.mdt.mt.gov/other/webdata/external/contractplans/reports/itemlist_english_2014.pdf
MDT Cost Estimating Information	http://www.mdt.mt.gov/business/contracting/cost.shtml
MDT Rumble Strip Guidance	http://www.mdt.mt.gov/other/webdata/external/cadd/design_memos/2015-07-08_RUMBLE_STRIP-4.pdf
Chapter 14 – Specifications/Special Provisions/Detailed Drawings	
MDT “Questions and Answers Forum”	http://www.mdt.mt.gov/business/contracting/qacurrent.shtml
MDT Standard Special Provisions	http://www.mdt.mt.gov/business/contracting/special_provisions.shtml
MDT Table of Contract Submittals	http://www.mdt.mt.gov/other/webdata/external/contractplans/submittals/contractor_submittals.pdf
MDT Standard Specifications	http://www.mdt.mt.gov/business/contracting/standard_specs.shtml
MDT Detailed Drawings	http://www.mdt.mt.gov/business/contracting/detailed_drawings.shtml
Experimental Projects Overview	http://www.mdt.mt.gov/research/projects/exp_overview.shtml

Appendix C

Quality Assurance/Quality Control Guidance

Appendix C is reserved for Quality Assurance/Quality Control (QA/QC) guidance that will be developed by MDT.

Appendix D

MDT Internal Coordination

Appendix D is reserved for additional information regarding MDT internal coordination.

Appendix E

Level of Service Criteria

The design team should coordinate with the Traffic and Safety Bureau for all traffic operational analyses conducted for the project and additional traffic operational information that may be needed for the design. The objective of conducting traffic operations analyses is to design the highway mainline and intersections to accommodate the selected design hourly volume (DHV) at the selected level of service (LOS). Appendix E provides the minimum LOS Criteria for various types of facilities. The detailed calculations, highway factors and methodologies are presented in the *Highway Capacity Manual* (*HCM*). During the analysis, the design service volume (or flow rate) of the facility is calculated. For various types of highway facilities, the *HCM* documents the measures of effectiveness that should be used in capacity analyses to determine level of service. For each facility type, the *HCM* provides the analytical tools necessary to calculate the numerical value of its respective measure of effectiveness. Additional design criteria for each facility type are presented in the *MDT Geometric Design Standards.*

Type of Facility	Level of Service Targets
Rural	
Freeways (NHS — Interstate)	B
Principal Arterials (NHS — Non-Interstate)	Level/Rolling: B; Mountainous: C
Minor Arterials	Level/Rolling: B; Mountainous: C
Collector Roads	C
Urban	
Freeways (NHS — Interstate)	B
Principal Arterials (NHS — Non-Interstate)	C
Minor Arterials	C
Collector Roads	D

Appendix F

Sight Distance

F.1 SIGHT DISTANCE OVERVIEW

Designing a roadway with adequate sight distance allows vehicles to travel safely and efficiently and perform necessary driving maneuvers. Chapter 2, Section 2.8 provides an overview of the various types of sight distance evaluated in road design. Appendix F provides additional detailed equations and Appendix K provides examples for calculating sight distance. The following types of sight distance will be discussed in this appendix:

1. Stopping Sight Distance
    a. Horizontal Sight Distance
    b. Vertical Sight Distance
2. Intersection Sight Distance
3. Passing Sight Distance
4. Decision Sight Distance

The design team should review the respective section in Chapter 2 and appendix material together to obtain an understanding of the overall approach for evaluating sight distance based on the project context.

F.2 STOPPING SIGHT DISTANCE

This section supplements information regarding stopping sight distance (SSD) provided in Chapter 2, Section 2.8.1.

F.2.1 Horizontal Stopping Sight Distance

This section supplements information regarding horizontal stopping sight distance (SSD) provided in Chapter 2, Section 2.8.1.1.

The needed clearance on the inside of the horizontal curve is calculated using Equation F.2-1 and is illustrated in Exhibit F-1:

$$M = R\left(1 - \cos\left(\frac{90° \times S}{\pi \times R}\right)\right)$$

Equation F.2-1

where:

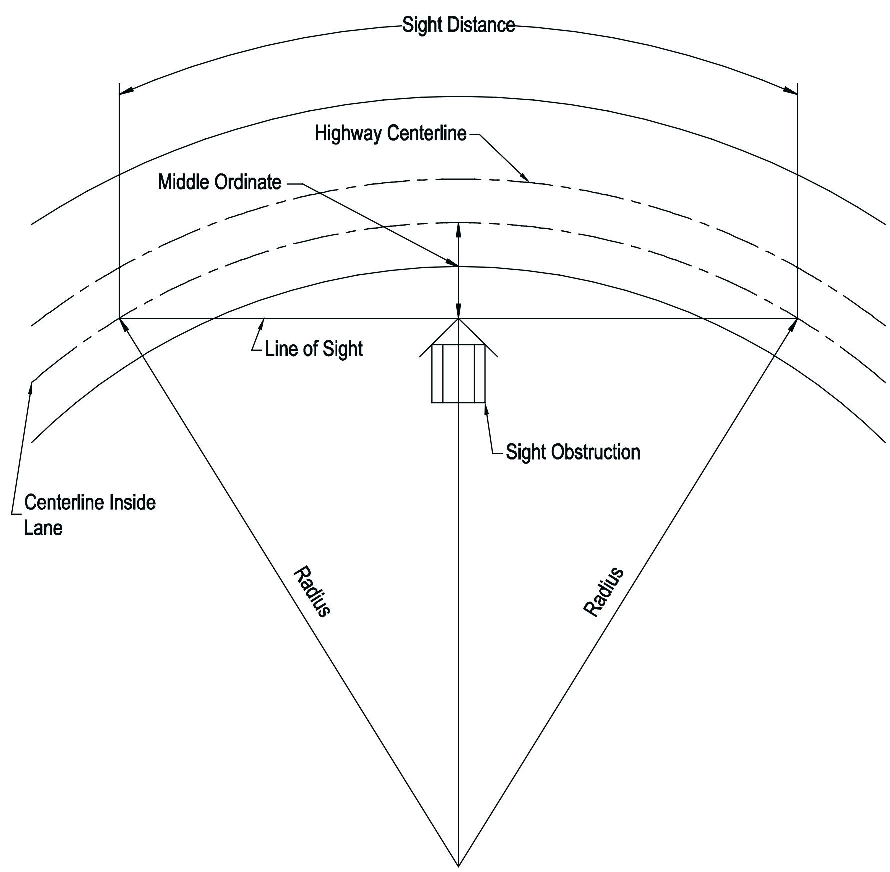
M = middle ordinate, or distance from the center of the inside travel lane to the obstruction, ft

R = radius of curve, ft

S = stopping sight distance, ft

Note: The expression $\left(\frac{90° \times S}{\pi \times R}\right)$ is in degrees, not radians.

Exhibit F-1
Horizontal Stopping Sight Distance



The M values as calculated using Equation F.2-1 apply between the Point of Curvature (PC) and Point of Tangency (PT) of a horizontal curve (or from the spiral to curve (SC) to the curve to spiral (CS)). In addition, some transition is needed on the entering and exiting portions of the curve. The design team should typically use the following steps:

1. Locate the point which is on the edge of travel lane and a distance of $S/2$ before the PC or SC.
2. Locate the point which is a distance M measured laterally from the center of the travel lane at the PC or SC.
3. Connect the two points located in Step 1 and 2. The area between this line and the roadway should be clear of all continuous sight obstructions.

4. A symmetrical application of Step 1 through 3 should be used beyond the PT or CS.

F.2.2 Vertical Alignment Sight Distance Considerations

When developing vertical alignments, the equations for determining the length of crest vertical curves that provide the desired sight distance are generally adequate to ensure a profile design meets the sight distance criteria. However, it is important to recognize that these equations are based on the geometry of a single parabolic curve on straight horizontal alignment, and may not provide a true representation of actual sight distance when shorter curves (relative to sight distance) are closely spaced. Similarly, roadside features where horizontal and vertical curves are used together can influence sight distance beyond what can be determined easily with equations. For these instances, checking sight distance graphically may be appropriate.

To better understand the limitations of the crest curve equations, it is helpful to understand when and how they are applied. The most familiar Equation F.2-2, is used when the length of the curve is equal to or greater than the sight distance needed. When S is less than L,

$$L = KA$$

Equation F.2-2

where:

L = length of vertical curve, feet

K = horizontal distance needed to produce a 1-percent change in gradient

A = algebraic difference between the two tangent grades, percent

$$K = \frac{S^2}{200(\sqrt{h_1} + \sqrt{h_2})^2}$$

Equation F.2-3

S = sight distance, feet

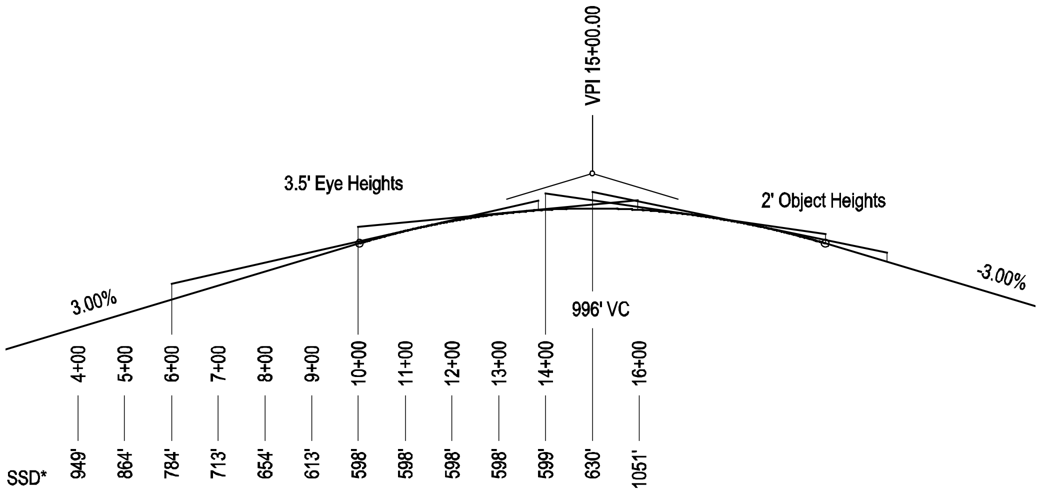
h_1 = height of eye above road surface, feet

h_2 = height of object above road surface, feet

Equation F.2-2 is often used for all crest curve lengths, and provides a conservative length requirement for smaller values of A. Unless influenced by a horizontal curve, sight distance is provided if this equation is satisfied for any length crest curve. When the sight distance provided by the curve is shorter than its length, the sight distance reduces to a minimum as a vehicle (eye) approaches the curve. The minimum sight distance is provided when both the eye and object are on the vertical curve, and begins to increase once the object reaches the tangent grade.

Exhibit F-2 illustrates stopping sight distance for a passenger car traveling over the minimum length curve for a 60 mph design speed, given a 6-percent algebraic difference in grades and adjusted for 3 percent downgrades. Stopping sight distance is shown at even stations, for a vehicle traveling left to right.

Exhibit F-2
Stopping Sight Distance over Minimum Length of Curve



*Horizontal Distance, Sloped Sight Line May Be Used But Must Be Adjusted For 10:1 Scale Shown

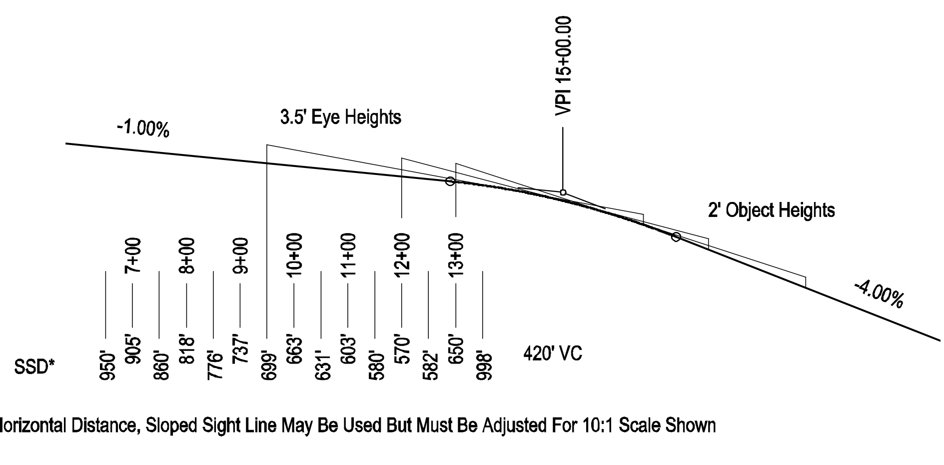
When S is greater than L,

Equation F.2-4

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

When the sight distance provided by the curve exceeds its length, the minimum sight distance is provided at one point, when the vertical curve is between the eye and the object, and each is on a tangent grade. The distance between the eye and curve and the object and curve when sight distance is a minimum depends on their heights. For passing sight distance, the heights are the same and the minimum sight distance occurs when the eye and object are equidistant from the curve. For stopping sight distance, this point occurs when the eye is about twice as far from the start of the curve as the object is from the end of the curve. Exhibit F-3 illustrates stopping sight distance at 50-foot intervals for a passenger car traveling from left to right.

Exhibit F-3
Stopping Sight Distance for Passenger Car



*Horizontal Distance, Sloped Sight Line May Be Used But Must Be Adjusted For 10:1 Scale Shown

Using Equation F.2-4, the minimum SSD is found to be about 570 feet, corresponding to a 60 mph design speed for level grades or 55 mph for the 4-percent down grade encountered for the direction shown. Assuming the full 4-

percent down grade through the breaking distance, stopping sight distance for 60 mph is 610 feet, which is provided except for about 200 feet between stations 10+50 and 13+00. Plotting sight lines graphically can show where sight distance is reduced, and can help the design team locate or check the sight distance at decision points. For symmetrical vertical curves, the sight distance in either direction is equal for points that are the same distance from the vertical point of intersection. In this case, the minimum stopping sight distance for a vehicle traveling back on stationing would be 570 feet at about station 18+00.

Rather than calculating a curve length using Equation F.2-4 and checking it against the sight distance to determine which equation is appropriate, check the threshold algebraic difference, shown as A' below, to determine which equation applies for a specific sight distance for intersecting grades. To determine this threshold value for a given sight distance and K-value, set L equal to S and solve for A:

$$A' = \frac{S}{K}$$

Equation F.2-5

Exhibit F-4 represents these threshold values for stopping sight on crest curves with level grades. Similar tables can be produced for sag curves, or for passing sight, decision sight, and any sight distance adjusted for grades.

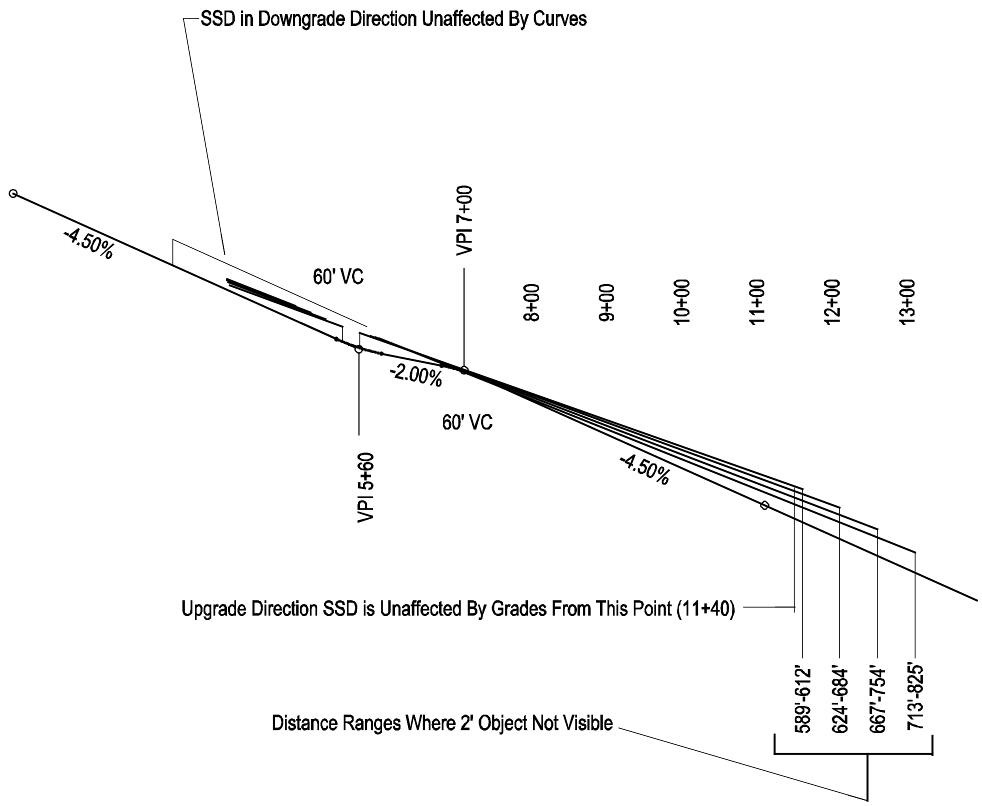
Design Speed (mph)	SSD Level (feet)	K (feet/1% change in grade)	A' (%)
15	80	3.0	26.98
20	115	6.1	18.77
25	155	11.1	13.92
30	200	18.5	10.79
35	250	29.0	8.63
40	305	43.1	7.08
45	360	60.1	5.99
50	425	83.7	5.08
55	495	113.5	4.36
60	570	150.6	3.79
65	645	192.8	3.35
70	730	246.9	2.96
75	820	311.6	2.63
80	910	383.7	2.37

Exhibit F-4 Stopping Sight Distance on Crest Curves with Level Grades

For algebraic differences greater than A', Equation F.2-2 should be used to determine curve length. Note that for very slow speeds, vertical sight distance is generally not a critical factor and the minimum length equation L=3V results in a longer length than either SSD equation for most values of A.

When shorter vertical curves are closely spaced, the standard equations may not be adequate to check available sight distance. These equations are based on the geometry of a parabola bounded by tangent grades that extend indefinitely, and cannot account for the effect that adjacent curves may have on the elevation of the eye or object. The most common application of shorter curves relative to sight distance is in urban environments where very short curves may be necessary to fit within vertical controls and for longer sight distances such as passing sight distance, decision sight distance, or sight distances adjusted for steep downgrades. Exhibit F-5 below may represent a case where a road grade is modified to accommodate an existing intersecting roadway.

Exhibit F-5 Stopping Sight Distance at an Intersecting Roadway



Based on Equation F.2-4, the crest curve at station 7+00 has a stopping sight distance of about 462 feet (228 feet based on Equation F.2-2). By checking the alignment graphically, it is shown that the SSD provided is unlimited through the curves for vehicles traveling left to right, and limited only by small gaps beyond 585 feet in the other direction.

F.3 INTERSECTION SIGHT DISTANCE

This section supplements information regarding intersection sight distance (ISD) provided in Chapter 2, Section 2.8.2.

As stated in Chapter 2, MDT uses gap acceptance as its basic methodology in the design of intersection sight distance. Additional information on gap acceptance is provided in the *AASHTO Green Book (2).*

The following sections describe the specific design considerations, criteria and equations for each of the following types of traffic control:

- No Traffic Control (AASHTO Case A)
- Stop Controlled/Traffic Signal Controlled (AASHTO Case B and D)

  - Vehicles Entering Major Roadway (AASHTO Case B1 and Case B2)
  - Straight Through Crossing Vehicle (AASHTO Case B3)
- Yield Control (AASHTO Case C)
- All-Way-Stop (AASHTO Case E)
- Stopped Vehicle Turning Left (AASHTO Case F)
- Channelized Right-Turn
- Roundabouts

F.3.1 No Traffic Control (AASHTO Case A)

As stated in Section 2.8.2, intersections between low-volume and low-speed roads/streets may have no traffic control. At these intersections, sufficient corner sight distance should be available to allow approaching vehicles to adjust their speed to avoid a crash, which is typically 50-percent of their mid-block running speed. Exhibit F-6 illustrates the ISD and sight lines between vehicles. Exhibit F-7 provides the ISD criteria for intersections with no traffic control. For approach grades greater than 3-percent, adjust the ISD values obtained in Exhibit F-7 with the applicable ratios in Exhibit F-8.

Exhibit F-6
Intersection Sight Distance Components (No Traffic Control)

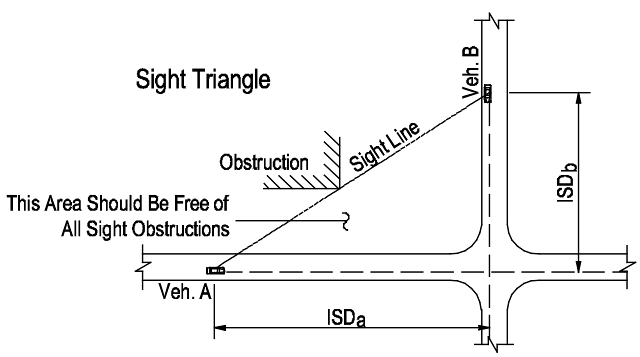


Exhibit F-7
Intersection Sight Distance Criteria (No Traffic Control)

Design Speed (mph)	Intersection Sight Distance (ft)
15	70
20	90
25	115
30	140
35	165
40	195
45	220
50	245

Note: For approach grades greater than 3-percent, multiply the sight distance values in this table by the appropriate adjustment factor from Exhibit F-8. The grade adjustment is based on the approach roadway grade only.

Exhibit F-8
Approach Factors for Approach Sight Distance Based on Approach Grade (No Traffic Control)

Approach Grade (%)	Design Speed (mph)										
	20	25	30	35	40	45	50	55	60	65	70
-6	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2
-5	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2
-4	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
-3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Note: Based on ratio of stopping sight distance on specified approach grade to stopping sight distance on level terrain. The grade adjustment is based on the approach roadway grade only.

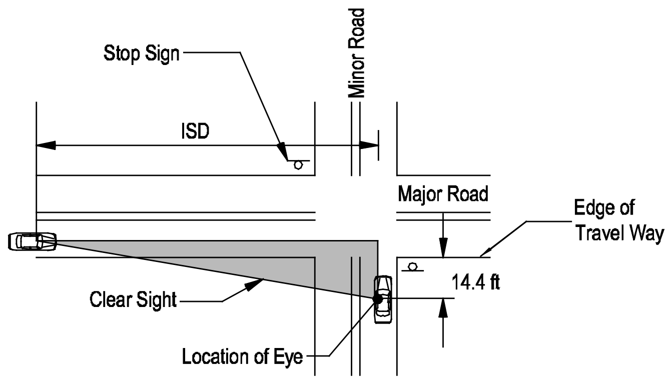
F.3.2 Stop Controlled/Traffic Signal Controlled (AASHTO Case B and Case D)

As stated in Chapter 2, Section 2.8.2, where traffic on the minor road of an intersection is controlled by stop signs, the driver of the vehicle on the minor road must have sufficient sight distance for a safe departure from the stopped position assuming that the approaching vehicle comes into view as the stopped vehicle begins its departure.

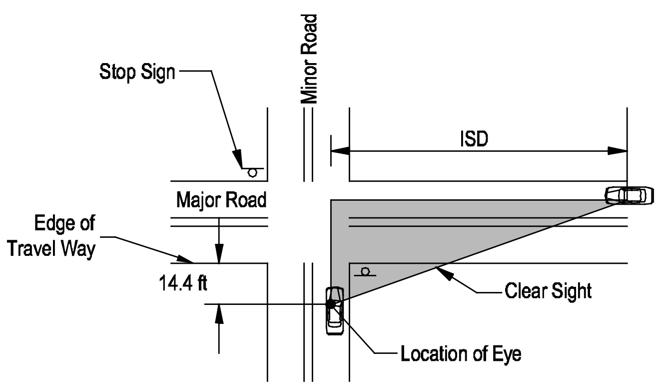
If a signalized intersection implements two-way flashing operations or right-turns are permitted on red, the stop-controlled criteria may apply for intersection sight distance.

MDT uses gap acceptance as the conceptual basis for its intersection sight distance (ISD) criteria at stop-controlled and traffic-signal controlled intersections. The intersection sight distance is obtained by providing clear sight triangles both to the right and left as shown in Exhibit F-9 (refer to Chapter 2, Exhibit 2-7).

Exhibit F-9
Clear Sight Triangles for Stop Controlled Intersections



Clear Sight Triangle For Viewing



Clear Sight Triangle For Viewing

The lengths of the legs of these sight triangles are determined as follows:

1. **Minor Road**. The length of the leg along the minor road is based on two parts. The first is the location of the driver's eye on the minor road. This is typically assumed to be 14.4 feet from the edge of traveled way (excluding shoulder and bicycle lanes) for the major road and in the center of the lane on the minor road; see Exhibit F-9. The second part is based on the distance to the center of the vehicle on the major road. For right-turning vehicles, this is assumed to be the center of the closest travel lane for vehicles approaching from the left. For left-turning vehicles, this is assumed to be the center of the closest travel lane for vehicles approaching from the right; see Exhibit F-9.
2. **Major Road**. The length of the sight triangle leg or ISD along the major road is determined using Equation F.3-1:

Equation F.3-1

$$ISD = 1.47V_{major}t_g$$

where:

ISD = length of sight triangle leg along major road, ft

V_{major} = design speed of major road, mph

t_g = gap acceptance time for entering the major road, s

The gap acceptance time (t_g) varies according to the design vehicle, the grade on the minor road approach, the number of lanes on the major roadway, the type of operation and the intersection skew.

Within this clear sight triangle, if practical, remove, lower any object or trim lower branches that obstruct the driver's view to 3.5 feet or below. These objects may include buildings, parked or turning vehicles, trees, hedges, tall crops, un-mowed grass, fences, retaining walls and the existing ground line. In addition, where an interchange ramp intersects the major road or crossroad near a bridge on a crest vertical curve, objects such as bridge parapets, piers, abutments or the crest vertical curve itself may restrict the clear sight triangle.

F.3.2.1 Vehicle Entering Major Roadway (AASHTO Case B1 and Case B2)

To determine the intersection sight distance for vehicles turning left or right onto the major road, the design team should use Equation F.3-1 and the gap acceptance time (t_g) presented in Exhibit F-10. Exhibit F-11, which solves Equation F.3-1, provides the ISD values for all design vehicles turning left on two-lane, level facilities. Exhibit F-12, which solves Equation F.3-1, provides the ISD values for all design vehicles turning right on two-lane, level facilities.

Exhibit F-10
Gap Acceptance Times for Right and Left Turn from a Minor Road

Design Vehicle	Left-Turn from Stop, Gap Acceptance Time (t_g) (s)	Right-Turn from Stop, Gap Acceptance Time (t_g) (s)
Passenger Car	7.5	6.5
Single-Unit Truck	9.5	8.5
Tractor/Semitrailer	11.5	10.5

Exhibit F-11
Two-Lane Intersection Sight Distances for Left-Turn from a Minor Road

Design Speed (V_{major}) (mph)	ISD (ft)		
	Passenger Cars	Single-Unit Trucks	Tractor/ Semitrailers
20	225	280	340
25	280	350	425
30	335	420	510
35	390	490	595
40	445	560	680
45	500	630	765
50	555	700	850
55	610	770	930
60	665	840	1015
65	720	910	1100
70	775	980	1185

Exhibit F-12
Two-Lane Intersection Sight Distances for Right-Turn from a Minor Road

Design Speed (V_{major}) (mph)	ISD (ft)		
	Passenger Cars	Single-Unit Trucks	Tractor/ Semitrailers
20	195	250	310
25	240	315	390
30	290	375	465
35	335	440	545
40	385	500	620
45	430	565	695
50	480	625	775
55	530	690	850
60	575	750	930
65	625	815	1005
70	670	875	1085

The design team should also consider the following:

1. **Multilane Facilities.** For multilane facilities, the gap acceptance times presented in Exhibit F-10 should be adjusted to account for the additional distance required by the turning vehicle to cross the additional lanes or median. The following will apply:
   a. **Left-Turns.** For left-turns onto multilane highways, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane, in excess of one, to be crossed by the turning vehicle. Assume that the left-turning driver will enter the left travel lane on the far side of the major road. For example, the gap acceptance time for a passenger car turning left onto an undivided six-lane facility would be 7.5 seconds plus 0.5 seconds for each of the two additional lanes needed to be crossed. The total gap time required is therefore 8.5 seconds.
   b. **Right-Turns**. Because the turning vehicle is assumed to be turning into the nearest right through lane, no adjustments to the gap times are required.
2. **Medians.** For a multilane facility which does not have a median wide enough to store a stopped vehicle, divide the median width by 12 feet to determine the corresponding number of lanes, and then use the criteria in Item 1a above to determine the appropriate time factor. On multilane facilities with a median wide enough to store the stopped vehicle, the design team should evaluate the move in two steps; see Exhibit F-13:
   a. First, with the vehicle stopped on the minor road (the bottom portion in Exhibit F-13), use the gap acceptance times and distances for a vehicle turning right (Exhibit F-10 and Exhibit F-12) to determine the applicable ISD. Under some circumstances, it may be necessary to check the crossing maneuver to determine if it is the critical movement. Crossing criteria are further discussed in the intersection design material presented in Chapter 6 and Section F.3.2.2 below.
   b. Then, with the vehicle stopped in the median (top portion in Exhibit F-13), assume a two-lane roadway design and use the gap acceptance times and distances for vehicles turning left (Exhibit F-10 and Exhibit F-11) to determine the applicable ISD.

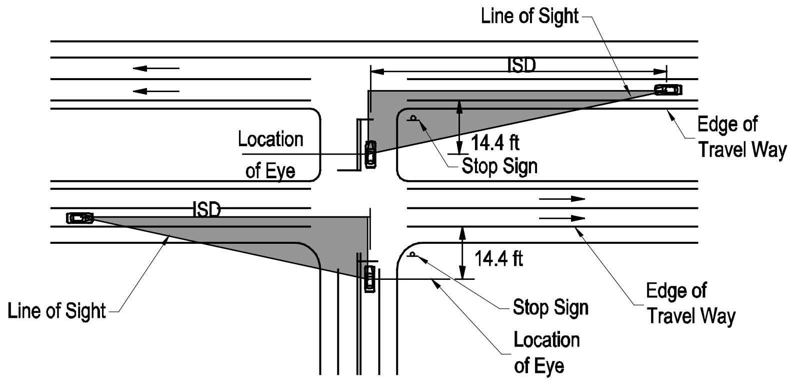


Exhibit F-13 Intersection Sight Distance for Divided Facilities

3. **Approach Grades.** If the approach grade on the minor road exceeds +3 percent upgrade, add the following times to the basic gap acceptance times in Exhibit F-10:
   a. **Left-Turns.** Multiply the percent grade on the approach by 0.2 and add this to the base time gap. This does not apply if the approach grade is negative.
   b. **Right-Turns.** Multiply the percent grade on the approach by 0.1 and add this to the base time gap. Use the adjusted t_g in Equation F.3-1 to determine the applicable ISD. Do not apply the grade adjustment if the approach grade is negative.
4. **Trucks.** At intersections near truck stops, interchange ramps, and grain elevators, the design team should consider using the truck as the design vehicle for determining the ISD. The gap acceptance times (t_g) for single-unit and tractor/semitrailer trucks are provided in Exhibit F-10. ISD values for level, two-lane roadways are presented in Exhibit F-11 and Exhibit F-12.
5. **Height of Eye/Object.** The height of eye for passenger cars is assumed to be 3.5 feet above the surface of the minor road. The height of object (approaching vehicle on the major road) is also assumed to be 3.5 feet. An object height of 3.5 feet assumes that a sufficient portion of the oncoming vehicle must be visible to identify it as an object of concern by the minor road driver. If there are enough trucks to warrant their consideration, assume an eye height of 7.9 feet for a tractor/semitrailer and 5.9 feet for single-unit trucks and buses. If a truck is the assumed entering vehicle, the object height will still be 3.5 feet for the passenger car on the major road.
6. **Skew.** At skewed intersections where the intersection angle is less than 60 degrees, adjustments may need to be made to account for the extra distance the vehicle needs to travel across opposing lanes. Using the procedures discussed in Item 1 above and/or Section F.3.2.2, determine the appropriate ISD value based on this extra travel distance.

F.3.2.2 Straight Through Crossing Vehicle (AASHTO Case B3)

In the majority of cases, the intersection sight distance for turning vehicles typically will provide adequate sight distance to allow a vehicle to cross the major road. However, in the following situations, the crossing sight distance may be the more critical movement:

1. Where left- and/or right-turns are not permitted from a specific approach and the crossing maneuver is the only legal or expected movement (e.g., indirect left turns);
2. Where the design vehicle must cross more than six travel lanes or, with medians, the equivalent distance; or
3. Where a substantial volume of heavy vehicles cross the highway and there are steep grades on the minor road approach.

Use Equation F.3-1 and the gap acceptance times (t_g) from Exhibit F-14 and the adjustment factors to determine the ISD for crossing maneuvers. Where medians are present, include the median width in the overall length to determine the applicable gap time. Divide this width by 12 feet to determine the corresponding number of lanes for the crossing maneuver.

Exhibit F-14
Gap Acceptance Times for Crossing Maneuvers on Two-Lane Facilities

Design Vehicle	Gap Acceptance Time (t_g) (sec)
Passenger Car	6.5
Single-Unit Truck	8.5
Tractor/Semitrailer	10.5

The following adjustments can be made to Exhibit F-14.

1. **Multilane Highway**. Where the design vehicle is crossing a major road with more than two lanes, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane in excess of two.
2. **Approach Grade.** If the approach grade on the minor road exceeds +3 percent upgrade, multiply the percent grade of the minor road approach by 0.2 and add it to the base gap acceptance time. Do not apply the grade adjustment if the approach grade is negative.

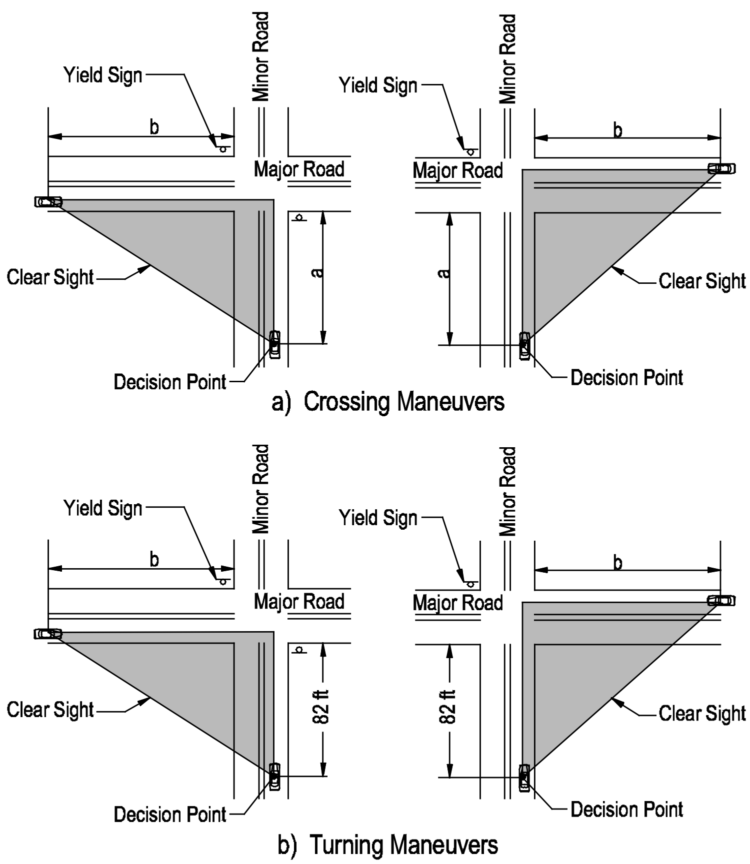
F.3.3 Yield Control (AASHTO Case C)

At intersections controlled by a yield sign (except roundabouts, which are described in Section F.3.7), drivers on the minor road will typically:

- slow down as they approach the major road, typically to 60-percent of the approach speed;
- based on their view of the major road, make a stop/continue decision; and
- either brake to a stop or continue their crossing or turning maneuver onto the major road.

Yield control criteria are based on a combination of the no traffic control ISD discussed in Section F.3.1 and the stop-controlled ISD as discussed in Section F.3.2. To determine the applicable clear sight triangles of the approaches, the following will apply; see Exhibit F-15:

Exhibit F-15 Intersection Sight Distance for Yield Control



1. **Crossing Maneuver**. Use the following to determine the legs of the clear sight triangle; see Exhibit F-15:
   a. **Minor Road.** The leg on the minor road approach can be determined directly from Exhibit F-16.
   b. **Major Road.** The leg on the major road is determined using Equation F.3-2 and the times listed in Exhibit F-16:

Equation F.3-2

$$t_g = t_a + \frac{w + L_a}{0.88(V_{minor})}$$

$$b = 1.47(V_{major})(t_g)$$

where:

b = length of leg of sight triangle along the major road, ft

t_g = travel time to reach and clear the major road in a crossing maneuver, s

t_a = travel time to reach the major road from the decision point for a vehicle that does not stop, s (use appropriate value for the minor-road design speed from Exhibit F-16, adjusted for approach grade, where appropriate)

w = width of intersection to be crossed, ft

L_a = length of design vehicle, ft

V_{minor} = design speed of minor road, mph

V_{major} = design speed of major road, mph

Exhibit F-16
ISD Assumptions for Yield Control Intersections Crossing Maneuvers

Major Road Design Speed (mph)	Approach Distance Along Minor Road (1) (a) (ft)	Travel Time From Decision Point to Major Road (t_a) (1) (2) (sec)
20	100	3.7
25	130	4.0
30	160	4.3
35	195	4.6
40	235	4.9
45	275	5.2
50	320	5.5
55	370	5.8
60	420	6.1
65	470	6.4
70	530	6.7

(1) For minor-road approach grades that exceed +3 percent upgrade, multiply by the appropriate adjustment factor from Exhibit F-8. Do not apply the adjustment factor to approaches with negative grades.

(2) Travel time applies to a vehicle that slows before crossing the intersection but does not stop.

2. **Turning Maneuvers.** For the turning left or right vehicle, the approach legs are determined as follows; see Exhibit F-15:
   a. **Minor Road.** The assumed turning speed from the minor road to the major road is 10 mph. This corresponds to an approach distance of 82 feet along the minor road leg.
   b. **Major Road.** To determine the legs along the major road, use the same procedures as discussed in Section F.3.2 for the stop controlled intersection, Equation F.3-1 and the gap acceptance time listed in

Exhibit F-17. Because the gap acceptance time is longer than the stop-controlled gap time, it will be unnecessary to determine the sight distance criteria for the vehicle which stops at the yield sign.

Exhibit F-17
Gap Acceptance Times for Turning Maneuvers at Yield Control Intersections

Design Vehicle	Gap Acceptance Time (t_g) (sec)
Passenger Car	8.0
Single-Unit Truck	10.0
Tractor/Semitrailer	12.0

If the approach grade on the minor road exceeds +3 percent upgrade, the following applies:

1. For right-turns, multiply the percent grade of the minor road approach by 0.1 and add it to the base gap acceptance time. Do not apply the grade adjustment if the approach grade is negative.
2. For left-turns, multiply the percent grade of the minor road approach by 0.2 and add it to the base gap acceptance time. Do not apply the grade adjustment if the approach grade is negative.

F.3.4 All-Way Stop (AASHTO Case E)

No additional information is provided in this appendix associated with this type of traffic control.

F.3.5 Stopped Vehicle Turning Left from Major Road (AASHTO Case F)

As stated in Section 2.8.2, at all intersections, regardless of the type of traffic control, the design team should consider the sight distance needs for a stopped vehicle turning left from the major road. An illustration of this situation is shown in Exhibit F-18. The driver must see straight ahead for a sufficient distance to turn left and clear the opposing travel lanes before an approaching vehicle reaches the intersection. In general, if the major highway has been designed to meet the stopping sight distance criteria, intersection sight distance will only be a concern where the major road is on a horizontal curve, where there is a median, or where there are opposing vehicles making left turns at the intersection.

Use Equation F.3-1 and the gap acceptance times (t_g) from Exhibit F-19 to determine the applicable intersection sight distances for the left-turning vehicle. Where the crossing vehicle must cross more than one lane, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane in excess of one. Where medians are present, the design team will need to consider their effect in the same manner as discussed in Section F.3.2. Exhibit F-20 provides the ISD values for all design vehicles and two common left-turning situations.

Exhibit F-18
Diagram for Intersection Sight Distance for a Stopping Vehicle Turning Left on a Major Road

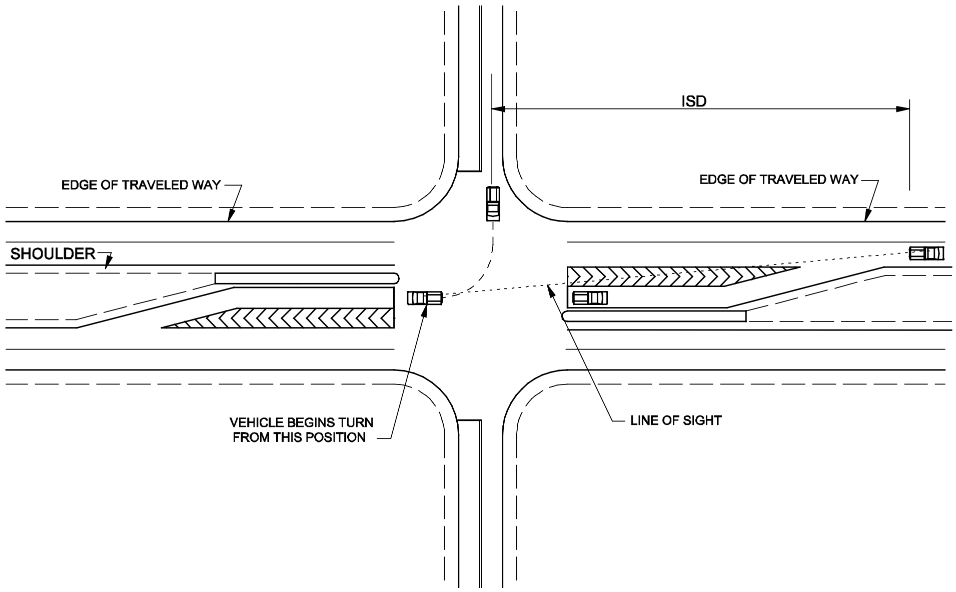


Exhibit F-19
Gap Acceptance Times for Left-Turning Vehicle on a Major Road

Design Vehicle	Gap Acceptance Time (t_g) (sec)
Passenger Car	5.5
Single-Unit Truck	6.5
Tractor/Semi-Trailer	7.5

Exhibit F-20 Intersection Sight Distances for Left-Turning Vehicles from a Major Road

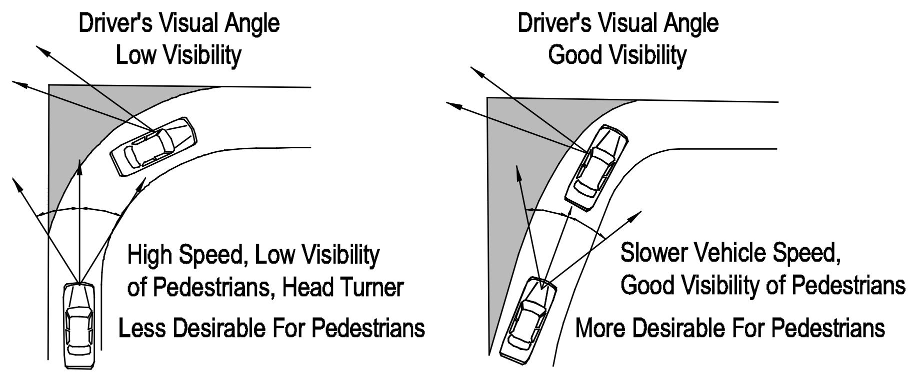
Design Speed (V_{major}) (mph)	ISD (ft)					
	Passenger Cars		Single-Unit Trucks		Tractor/Semitrailers	
	Cross 1 lane	Cross 2 lanes	Cross 1 lane	Cross 2 lanes	Cross 1 lane	Cross 2 lanes
20	165	180	195	215	225	245
25	205	225	240	265	280	305
30	245	265	290	320	335	365
35	285	310	335	375	390	425
40	325	355	385	425	445	485
45	365	400	430	480	500	545
50	405	445	480	530	555	605
55	445	490	530	585	610	665
60	490	530	575	640	665	725
65	530	575	625	690	720	785
70	570	620	670	745	775	845
75	610	665	720	795	830	905
80	650	710	765	850	885	965

F.3.6 Channelized Right-Turn

Sight lines at a channelized right-turn should be clear of obstructions and provide sufficient visibility for various users.

As stated in Section 2.8.2, when designing a channelized right-turn lane at an intersection, the sight distance for the approaching vehicles and sight distances for the pedestrians approaching the intersection should be considered. Sight lines should be clear of obstructions and provide sufficient visibility for various users. Exhibit F-21 illustrates two different designs for a channelized right-turn and the visibility from each design *(4)*. The image on the left shows a circular curve where motorists in the channelized right-turn have an abrupt angle (looking over their shoulder) to identify a gap in the oncoming traffic. The image on the right shows an arrangement of compound curves to slow vehicles in the vicinity of the crosswalk, as well as provide an appropriate angle for sight distance when turning right onto the cross street.

Exhibit F-21
Intersection Sight Distance for a Channelized Right-turn

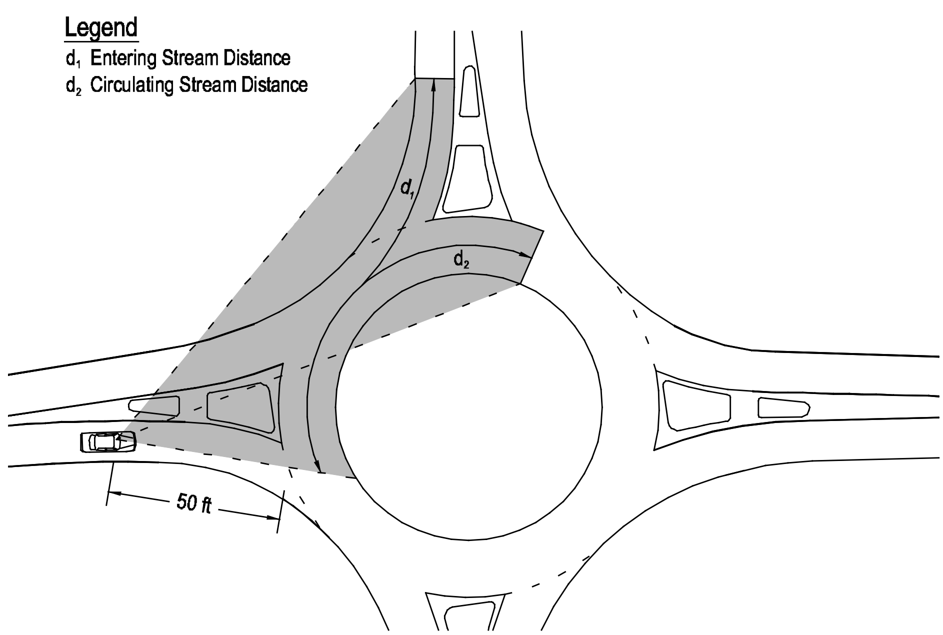


F.3.7 Roundabouts

A stated in Chapter 2, Section 2.8.2, intersection sight distance should be evaluated at the entries of a roundabout. At roundabouts, the sight triangle should follow the curvature of the roadway, and thus distances should be measured not as straight lines but as distances along the vehicular path. *NCHRP Report 672: Roundabouts An Information Guide, Second Edition* describes the method for evaluating intersection sight distance at roundabouts, which is described below *(3)*.

Exhibit F-22 (refer to Chapter 2, Exhibit 2-8) presents a diagram showing the method for determining intersection sight distance.

Exhibit F-22
Intersection Sight Distance at Roundabouts



As shown in Exhibit F-21, there are two conflicting approaches on the sight triangle that should be evaluated, which are further described below.

1. **Length of Approach Leg.** The length of the approach leg of the sight triangle should be limited to 50 feet. This distance encourages vehicles to slow down prior to entering the roundabout, which supports the need to slow down and yield at the roundabout entry. This also allows drivers to identify any potential pedestrians crossing in advance of the roundabout

entry. If the approach leg of the sight triangle is greater than 50 feet, landscaping can be added to restrict sight distance to the minimum requirements *(3)*.

2. **Length of Conflicting Leg.** A vehicle approaching the entry of a roundabout may encounter conflicting vehicles within the circulatory roadway of the roundabout and vehicles entering the roundabout from the immediate upstream entry. The length of the conflicting leg is calculated using Equations F.3-3 and F.3-4.

Equation F.3-3

$$d_1 = 1.47\left(V_{major,\ entering}\right)(t_c)$$

Equation F.3-4

$$d_2 = 1.47(V_{major,\ circulating})(t_c)$$

Where:

d_1 = length of the entering leg of sight triangle, ft

d_2 = length of the circulating leg of sight triangle, ft

V_{major} = design speed of conflicting movement, mph

t_c = critical headway for entering the major road, s, equal to 5.0s.

The design speed of the conflicting movements ($V_{major,\ entering}$ and $V_{major,\ circulating}$) is estimated using the following. Additional information regarding the speeds described below (R_1, R_2, and R_4) is illustrated in Chapter 6, Exhibit 6-13 and further described in *NCHRP Report 672 (3).*

Additional information regarding the speeds described below (*R_1*, *R_2*, and *R_4*) is illustrated in Chapter 6, Exhibit 6-13 and further described in *NCHRP Report 672 (3).*

1. **Entering stream.** This consists of the vehicles from the immediate upstream entry. The speed for this movement can be approximated by taking the average of the theoretical entering (R_1) speed and the circulating (R_2) speed.
2. **Circulating stream.** This consists of the vehicles that enter the roundabout prior to the immediate upstream entry. This speed can be approximated by taking the speed of left-turning vehicles (path with radius R_4).

The critical headway for entering the major road (t_c) is based on the amount of time required for a vehicle to safely enter the conflicting stream. This value is typically 5.0 seconds, which is based on the critical headway required for passenger cars. Exhibit F-23 summarizes the length of conflicting leg for various approach speeds of an intersection sight triangle *(3)*.

**Exhibit F-23
Conflicting Leg for Sight Triangle at Roundabouts**

Conflicting Approach Speed (mph)	Distance (ft)
10	73.4
15	110.1
20	146.8
25	183.5

30	220.2

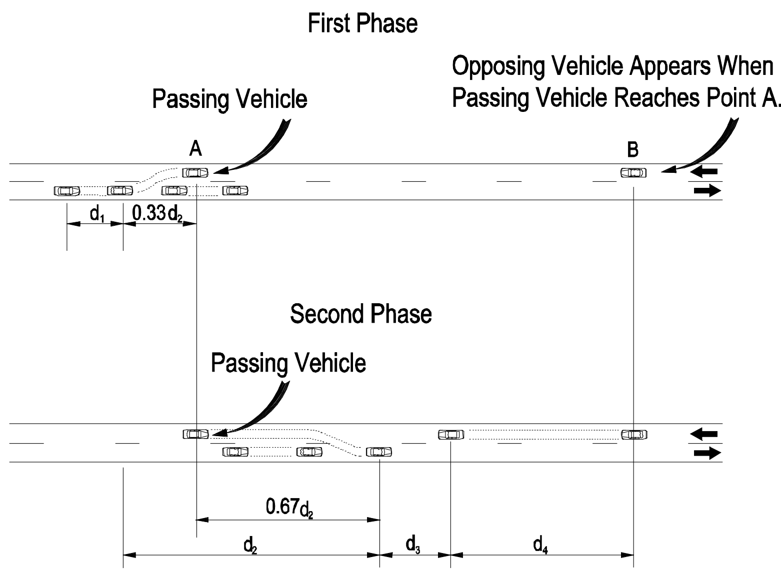
After the stopping sight distance (discussed in Section F.2) and the intersection sight distance at a roundabout have been evaluated separately, the sight triangles should be overlaid onto a single drawing to allow for an overall combined check for each approach. This can help provide design guidance for landscaping design and other treatments. Additional information regarding roundabout design is provided in the intersection design material presented in Chapter 6.

F.4 PASSING SIGHT DISTANCE

This section supplements information regarding passing sight distance (PSD) provided in Chapter 2, Section 2.8.3.

The minimum passing sight distance for two-lane highways is determined from the sum of four distances as illustrated in Exhibit F-24 (refer to Chapter 2, Exhibit 2-9).

Exhibit F-24
Elements of Passing Distance
(Two-Lane Highways)



The following discussion provides the basic assumptions used to develop passing sight distance values for design.

1. **Initial Maneuver Distance (*d_1*).** As stated in Chapter 2, Section 2.8.3, this is the distance traveled during the perception and reaction time and during the initial acceleration to the point of encroachment on the left lane. For the initial maneuver, the overtaken vehicle is assumed to be traveling at a uniform speed.

   The average speed of the passing vehicle is assumed to be approximately 9 mph greater than the overtaken vehicle. Use Equation F.4-1 to determine d_1:

$$d_1 = 1.47t_1\left(v - m + \frac{at_1}{2}\right)$$

Equation F.4-1

The AASHTO Green Book can provide additional information on the variables described *(2)*.

where:

t_1 =	time of initial maneuver, s
v =	average speed of passing vehicle, mph
m =	difference in speed of passed vehicle and passing vehicle, mph
a =	average acceleration, mph/s

2. **Distance of Passing Vehicle in Left Lane (d_2).** As stated in Chapter 2, Section 2.8.3, this is the distance traveled by the passing vehicle while it occupies the left lane. Use Equation F.4-2 to determine d_2:

$$d_2 = 1.47vt_2$$

Equation F.4-2

where:

v =	average speed of passing vehicle, mph
t_2 =	time passing vehicle occupies the left lane, s

3. **Clearance Distance (d_3).** As stated in Chapter 2, Section 2.8.3, this is the distance between the passing vehicle at the end of its maneuver and the opposing vehicle.
4. **Opposing Vehicle Distance (d_4).** As stated in Chapter 2, Section 2.8.3, this is the distance traveled by an opposing vehicle during the time the passing vehicle occupies the left lane. The opposing vehicle appears after approximately one-third of the passing maneuver (d_2) has been accomplished. The opposing vehicle is assumed to be traveling at the same speed as the passing vehicle.

Exhibit F-5 (refer to Chapter 2, Exhibit 2-10) provides the minimum passing sight distance for design on two-lane, two-way highways. The AASHTO Green Book can provide additional information on the variables described *(2)*.

Exhibit F-25
Minimum Passing Sight Distance (Two-Lane Highways)

Design Speed (mph)	Assumed Speeds: Passed Vehicle (mph)	Assumed Speeds: Passing Vehicle (mph)	Minimum PSD for Design (ft)
30	18	30	500
35	23	35	550
40	28	40	600
45	33	45	700
50	38	50	800
55	43	55	900
60	48	60	1000
65	53	65	1100
70	58	70	1200
75	63	75	1300
80	68	80	1400

F.5 DECISION SIGHT DISTANCE

This section supplements information regarding decision sight distance (DSD) provided in Chapter 2, Section 2.8.4.

Equation F.5-1 describes the decision sight distance for avoidance maneuvers A and B. Refer to Exhibit 2-11 in Chapter 2 that summarizes the *DSD* for various speeds and maneuvers. For these avoidance maneuvers, the braking distance is added to the pre-maneuver component.

Equation F.5-1

$$DSD = 1.47Vt + 1.075\frac{V^2}{a}$$

where:

DSD = decision sight distance, ft

t = pre-maneuver time, s

V = design speed, mph

a = driver deceleration, ft/s^2

Equation F.5-2 describes the decision sight distance for avoidance maneuvers C, D and E. For these avoidance maneuvers, the braking distance is replaced with a maneuver distance based on maneuver times that decrease with increasing speed.

$$DSD = 1.47Vt$$

Equation F.5-2

where:

DSD = decision sight distance, ft

t = total pre-maneuver and maneuver time, s

V = design speed, mph

Additional information on decision sight distance is provided in Chapter 2, Section 2.8.4.

F.6 REFERENCES

1. Montana Department of Transportation (MDT). *Geometric Design Standards.* Helena, MT: MDT, 2016.
2. AASHTO. *A Policy on Geometric Design of Highways and Streets.* Washington, D.C.: AASHTO, 2011.
3. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide, 2nd ed.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
4. Harwood, D. and C. Hoban. *Low Cost Methods for Improving Traffic Operations on Two-Lane Roads*, Report No. FHWA-IP-87-2. Washington, D.C.: FHWA, 1987.

Appendix G

Supplemental Horizontal Alignment Information

Appendix G contains supplemental information associated with Chapter 3: Horizontal Alignment, which includes the following:

- Superelevation Axis of Rotation
- Rounding Curve and Alignment Data
- Rounding of Stationing and Bearings
- Compound Curve Applications

G.1 SUPERELEVATION AXIS OF ROTATION

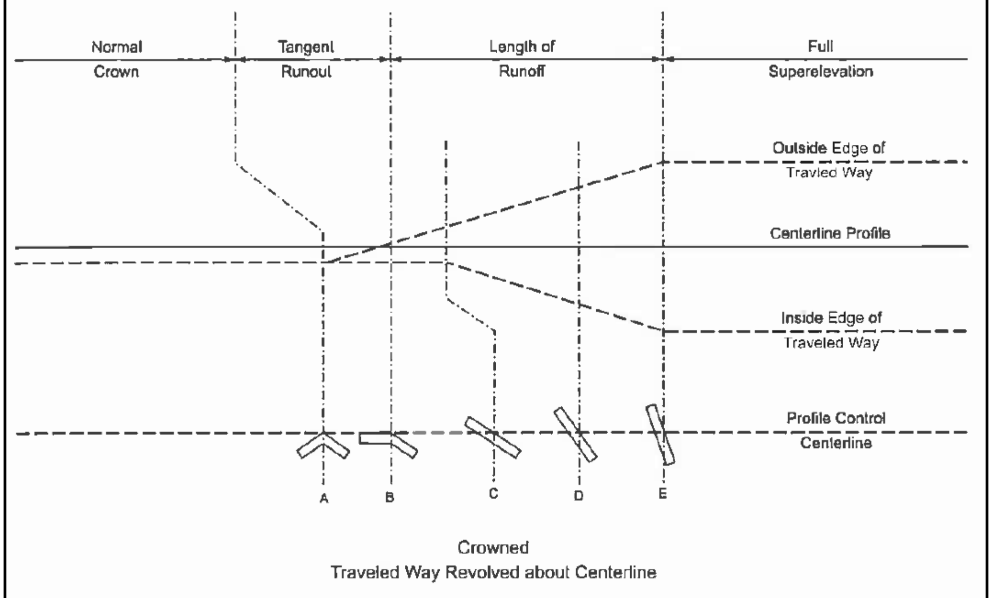
Superelevation axis of rotation should typically be about the centerline profile (Method A below) for all rural or urban roadways, except for those roadways with a median more than 10 feet wide. One of AASHTO Cases I-III should be applied, for roadways with a median more than 10 feet wide. Chapter 3, Section 3.3.5 provides additional details on MDT's approach for axis of rotation. The 2011 *AASHTO A Policy on Geometric Design of Highways and Streets* (Green Book) has four methods for setting the axis of rotation, which are described below.

- **Method A: Rotation about the centerline profile.** This method rotates the traveled way about the centerline profile. The centerline profile remains fixed while the inside-edge profile is dropped below the centerline and the outside-edge profile is raised above the centerline, thus creating the least amount of distortion to the edge of the roadway.
- **Method B: Rotation about the inside-edge of pavement.** This method was the previously preferred method for axis of rotation and rotates the traveled way about the inside-edge profile. The inside edge of traveled way, between the travel lane and shoulder, remains fixed while the centerline is raised above the inside edge and the outside edge is raised above the centerline.
- **Method C: Rotation about the outside-edge profile.** This method rotates the traveled way about the outside-edge profile. It is similar to Method B, except the outside edge of traveled way, between the travel lane and shoulder, remains along a fixed plane while the centerline and inside-edge profile are lowered.

- **Method D: Straight cross slope rotated about the outside-edge profile.** This method rotates the traveled way with a straight cross slope about the outside edge of traveled way profile. This method is most common for divided highway facilities where each direction is sloped to drain to the median.

Exhibits illustrating each method are shown below, which are excerpts from the *AASHTO Green Book*.

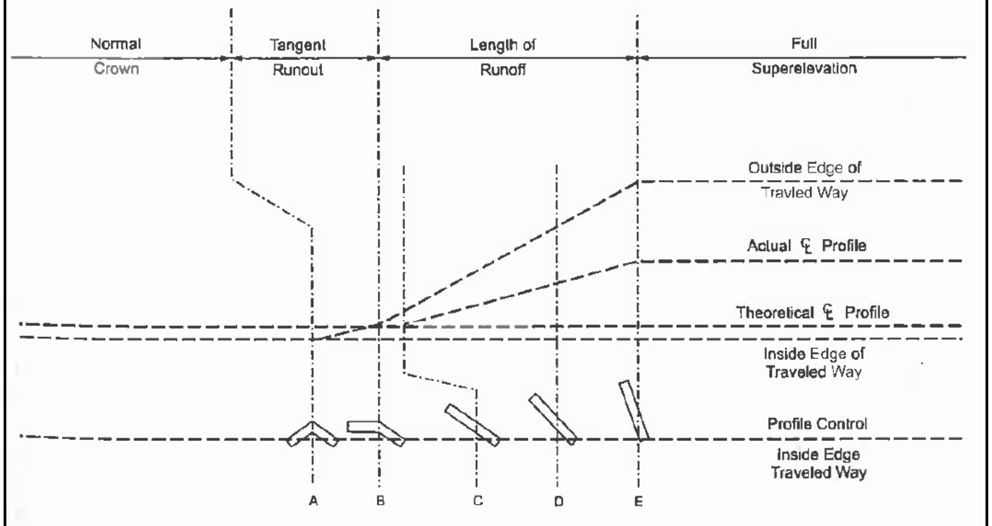
Exhibit G-1
Excerpt from *AASHTO Green Book* – Axis of Rotation: Method A



Crowned
Traveled Way Revolved about Centerline

– A –

Exhibit G-2
Excerpt from *AASHTO Green Book* – Axis of Rotation: Method B



Crowned
Traveled Way Revolved about Inside Edge

– B –

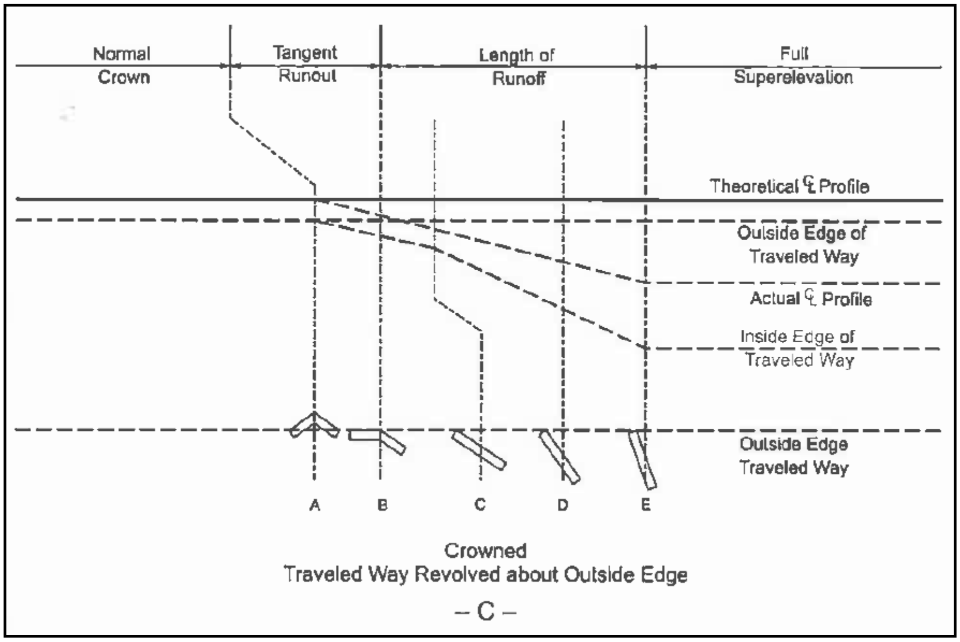


Exhibit G-3
Excerpt from *AASHTO Green Book* – Axis of Rotation: Method C

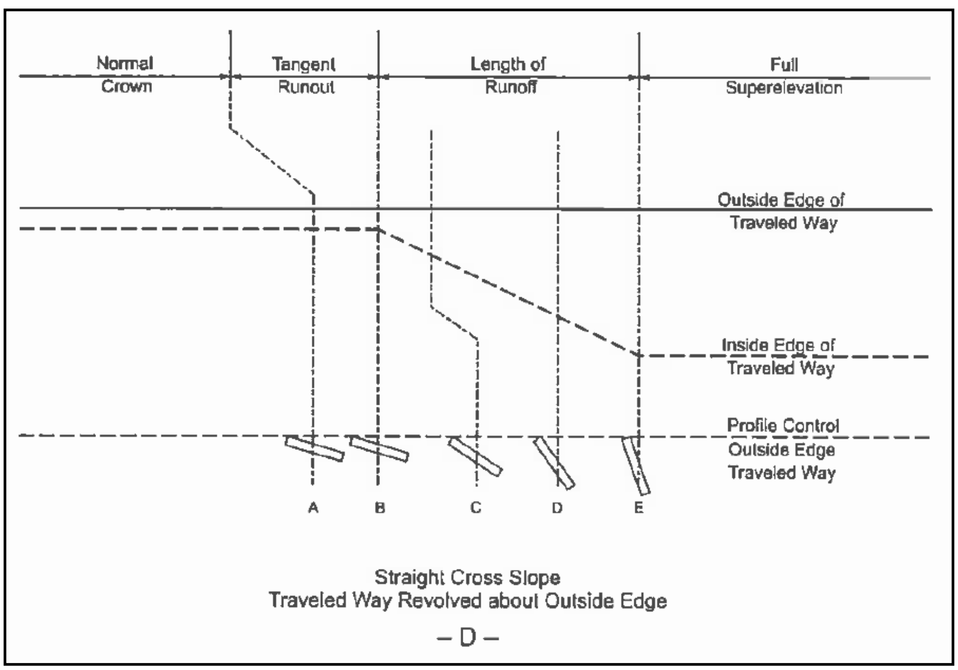


Exhibit G-4
Excerpt from *AASHTO Green Book* – Axis of Rotation: Method D

G.2 ROUNDING CURVE AND ALIGNMENT DATA

G.2.1 For a New Horizontal Curve

The following summarizes MDT's practices for presenting data for a new horizontal curve on the roadway plans:

1. **Deflection Angle**. These should be recorded in degrees rounded to the nearest second of a degree.
2. **Linear Distances**. These should be recorded in feet rounded to the nearest one hundredth of a foot (i.e., two decimal places).
3. **Curve Radii**. Where rounding is necessary, radii should be recorded in feet rounded to the nearest 5 feet.

When using computer-generated curve data, consider the implications of rounding off the data according to the above criteria. To ensure mathematical consistency, the following procedure should be used when defining the horizontal alignment.

Input:

1. Store given PI coordinates.
2. Inverse PI coordinates to produce distance and bearing between PIs.
3. Round distance to two places (0.01). Round bearings to nearest second (01").
4. Define the horizontal alignment by traversing PI to PI using the rounded distance and bearing.
5. Set station preference to two places (0.01).
6. Set distance preference to three places (0.001).

Output:

1. Rounded bearings to nearest second (to be shown on plans).
2. Rounded control point (PI, PC, PT or TS) stations to two places (to be shown on plans).
3. Adjusted control point coordinates to three places (to be shown on coordinate table).
   a. Curve data to four places that must be rounded to two places before placing on plans. For example, T, L, L_c. Minor adjustments to the control point stations may be necessary to reflect the rounded curve data.

G.2.2 For an Existing Horizontal Curve

For existing horizontal curves, MDT's rounding practices for presentation on the roadway plans are:

1. **Deflection Angle.** These should be recorded in degrees rounded to the nearest second of a degree.

2. **Linear Distances.** These should be recorded in feet rounded to the nearest one hundredth of a foot (i.e., two decimal places).

3. **Curve Radii.** Rounding will be determined by the Project Scope of Work as follows:

   a. **Overlay and Widening.** Where an existing metric horizontal curve will be retained in the project, calculate the US Customary radius from the known radius and round to three decimal places. The *T* and *L* distances are then calculated based on the US Customary radius and rounded to the nearest 0.01 of a foot.

   b. **Reconstruction.** Where the alignment for a reconstruction project will approximate the existing alignment, the radii of the reconstructed curve may be rounded to the nearest 5 feet. The *T* and *L* distances are then calculated based on the US Customary radius and rounded to the nearest 0.01 of a foot.

G.3 ROUNDING OF STATIONING AND BEARINGS

The following will apply to projects where control points are used to establish horizontal alignment:

1. **Rounding.** All stationing will be rounded to the nearest hundredth of a foot (i.e., two decimal places). All bearings will be rounded to the nearest second of a degree. When rounding computer-generated bearings, ensure that the rounded numbers for bearings are mathematically consistent.
2. **Coordinates**. Prepare a table of coordinates for the linear and level data sheet. The table will illustrate the coordinate values for all control points for either the staked centerline or control traverse survey and for the projected centerline. The control points will include the project beginning and ending points; the PC, PI and PT for simple curves; the TS, SC, (Master) PI, CS and ST for spiral curves; and all equations. All coordinates must be computed to at least four decimals and rounded in the table to the nearest three decimals (.001).

For projects using the as-built plans as the basis of horizontal alignment (typically overlay projects), retain the degree of accuracy shown on the as-built plans for US Customary as-builts. If as-builts are metric, soft convert the as-built stationing to US Customary and round as described above. Also, when existing right-of-way (R/W) plans are used to describe additional R/W acquisition, ensure that the accuracy of the stationing and bearings matches that of the old R/W plans.

G.4 COMPOUND CURVE APPLICATIONS

Compound curves are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other. Compound curves are most commonly used for transitioning low-speed roadways at intersections (for example, ramps, slip lanes), but can also be used on the mainline of low-speed urban roadways, particularly as a practical design alternative to spiral transitions. The design team should avoid a curve radius misleading the motorist’s expectation of the sharpness of another curve radius within the compound curve. Therefore, compound curves on the mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve ($R_1 \leq 1.5R_2$, where R_1 is the flatter curve). Superelevation transition lengths can be applied to the approaching and exiting curves in the same manner as applied to single curves. See Appendix K for examples of the application and calculation of compound curves.

The design team should exercise caution using compound curves. Compound curves are generally not a preferred horizontal alignment design feature. However, circumstances do arise that preclude other preferred curve options from being feasible. Geographic features, such as railroads, waterways and topography and/or right-of-way restrictions are some conditions that can introduce substantial project risk. Compound curves can be an appropriate response strategy in these circumstances to mitigate risk. When compound curves are applied, they should be discussed at the milestone reviews and justified in the milestone reports. See Chapter 3, Section 3.1.1 for design guidance.

The most common use of compound circular curves is in the design of turning roadways, such as slip lanes and interchange ramps, where vehicles are moving from one roadway to another, and a change in design speed is anticipated. An interchange loop ramp for example, may utilize a three-centered compound curve of decreasing, then increasing radii to provide for a large turning movement with varying speed as shown in Exhibits G-5 and G-6. The radii correspond to the vehicles deceleration and subsequent acceleration through the maneuver.

Exhibits G-5 and G-6 show examples for both three-centered and two-centered compound curves.

Exhibit G-5
Three-Centered Compound Curve

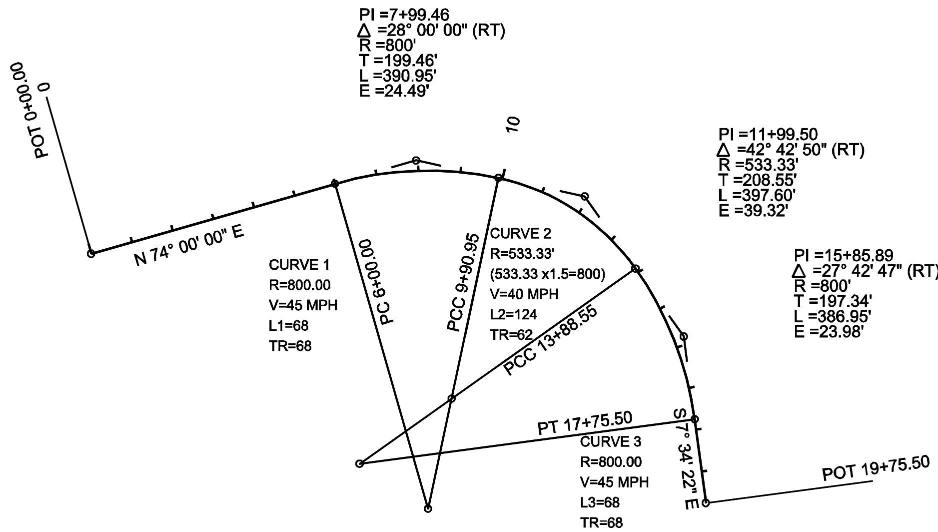
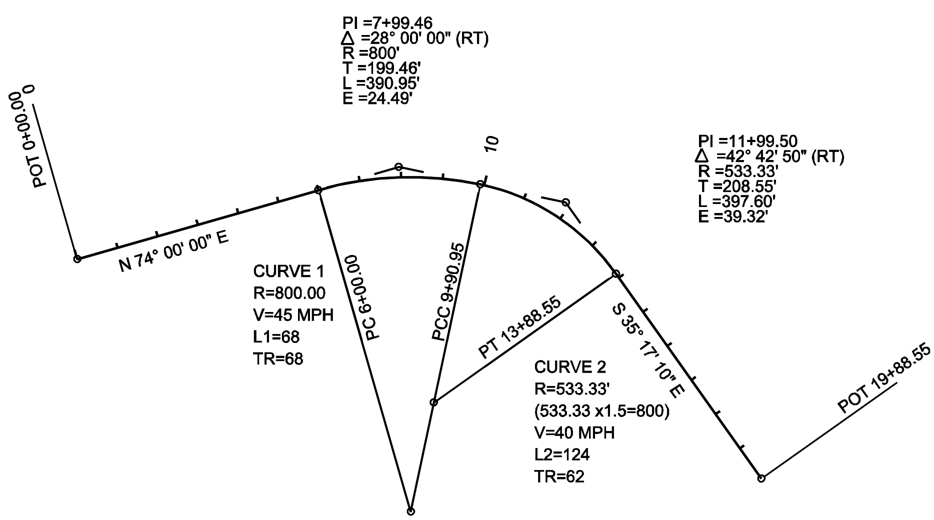


Exhibit G-6
Two-Centered Compound Curve



Appendix H

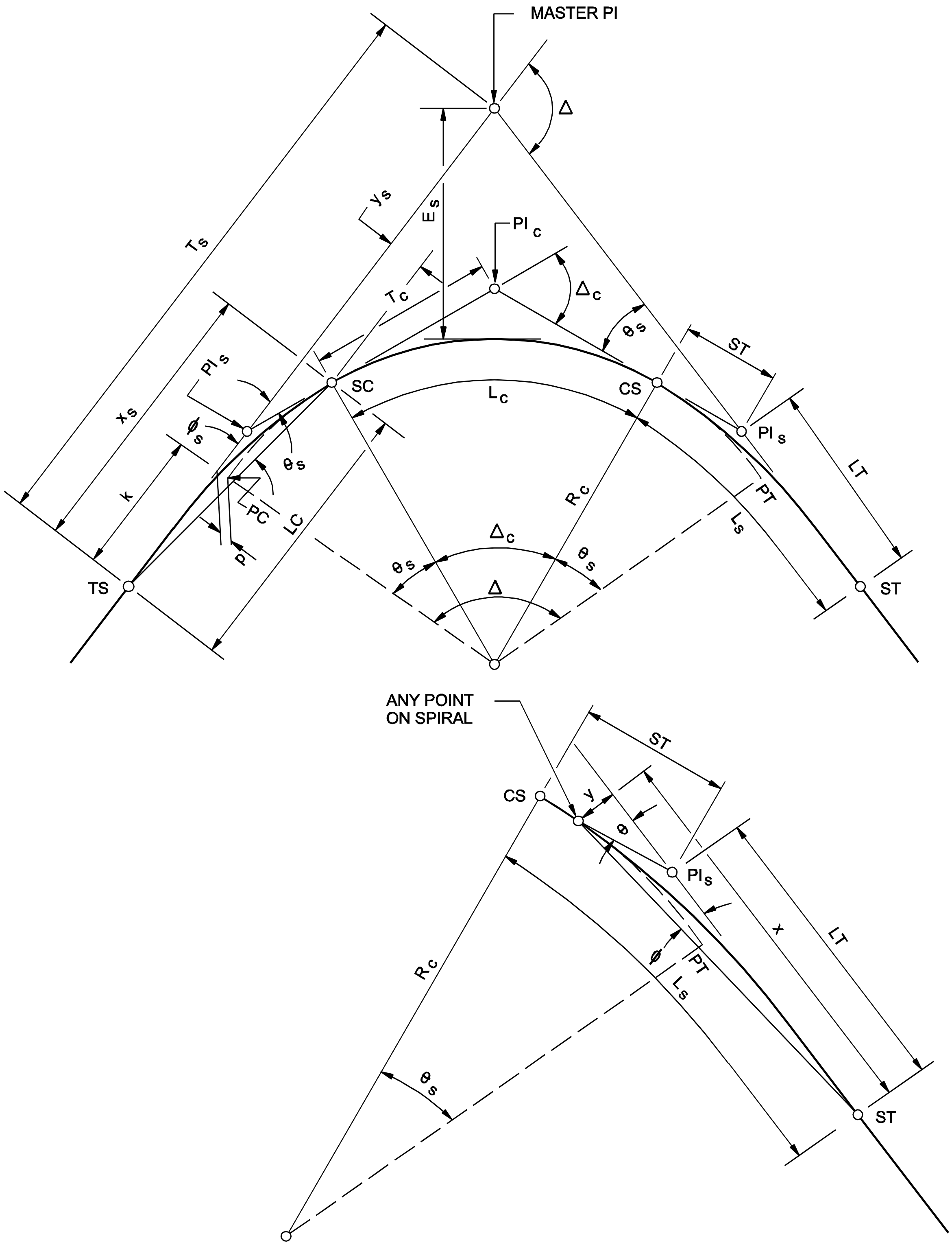
Horizontal and Vertical Alignment Equations

Appendix H contains additional horizontal and vertical alignment equations that correspond to Chapters 3 and 4, as well as the horizontal and vertical alignment example calculations shown in Appendix K.

H.1 SPIRAL CURVES

The following sections provide information on spiral curve elements, nomenclature and formulas.

H.1.1 Spiral Curve Elements



H.1.2 Spiral Curve Nomenclature

Master *PI* = Point of intersection of the main tangents.

PC = Point at which the circular curve extended becomes parallel to the line from *TS* to the Master *PI.*

PT = Point at which the circular curve extended becomes parallel to the line from *ST* to the Master *PI.*

PI_c = Point of intersection of circular curve tangents.

PI_s = Point of intersection of the main tangent and tangent of circular curve.

TS = Tangent to spiral; common point of spiral and near transition.

SC = Spiral to curve; common point of spiral and circular curve of near transition.

CS = Curve to spiral; common point of circular curve and spiral of far transition.

ST = Spiral to tangent; common point of spiral and tangent of far transition.

R_c = Radius of the circular curve (*SC* to *CS*), ft

L_s = Length of spiral, ft

L_c = Length of circular curve, ft

T_s = Tangent distance from Master *PI* to *TS* or *ST*, ft

T_c = Tangent distance from *SC* or *CS* to PI_c, ft

E_s = External distance from Master *PI* to midpoint of circular curve, ft

LT = Long tangent of spiral only, ft

ST = Short tangent of spiral only, ft

LC = Long chord of spiral, ft.

p = Offset distance from the main tangent to the *PC* or *PT* of the circular curve produced, ft

k = Distance from *TS* to point on main tangent opposite the *PC* of the circular curve produced, ft

Δ = Total deflection angle between main tangents of the entire curve, degrees

Δ_c = Deflection angle between tangents at the *SC* and the *CS* or the central angle of the circular curve, degrees

θ_s = Central angle between the tangent of the complete curve and the tangent at the *SC;* i.e., the "spiral angle," degrees

ϕ_s = Spiral deflection angle from tangents at *TS* to *SC* or from *ST* to *CS*, degrees

$x_s y_s$ = Coordinates of *SC* from the *TS* or of *CS* from *ST.*

L = Length of spiral arc from the *TS* or *ST* to any point on the spiral, ft

x,y = Coordinates to any point on the spiral from TS or ST.

ϕ = Spiral deflection angle from *TS* or *ST* to any point on spiral, degrees

θ = The central angle of spiral arc L to any point on the spiral, degrees. θ equals θ_s when L equals L_s.

H.1.3 Spiral Curve Formulas

CURVE EQUATIONS

1. $\theta_S = (L_s / R_C)(90/\pi)$
2. $\Delta_C = \Delta - 2\theta_S$
3. $L_C = \frac{\Delta_C}{360} 2\pi R_C$
4. $T_S = (R_C + p)\tan(\Delta/2) + k$
5. $E_S = (R_C + p)(1/\cos(\Delta/2) - 1) + p =$
$\left[\frac{(R_C + p)}{\cos(\Delta/2)} - (R_C + p)\right] + p$

6. p and k are obtained from *Route Location and Design*, Hickerson (pg. 375).

$$p = L_s\left[0.0014544\ \theta_s\right] - 1.582315\ \theta_s^{\ 3} \times (10)^{-8} + 1.022426\ \theta_s^{\ 5} \times (10)^{-13} - \ldots$$

$$k = L_s\left[0.5 - 5.076957\ \theta_s^{\ 2} \times (10)^{-6} + 4.295915\ \theta_s^{\ 4} \times (10)^{-11} - \ldots\right]$$

SPIRAL EQUATIONS

Correction for C in Formula : $\varphi = \frac{\theta}{3} - C$								
θ_S in Degrees	15	20	25	30	35	40	45	50
C in Minutes	0.2	0.4	0.8	1.4	2.2	3.4	4.8	6.6

7. $\varphi(approx.) = \frac{\theta}{3}\ ,\ if\ \ \theta_S < \ 15°00'$
8. $\varphi(approx.) = \frac{\theta}{3} - C,\ \ if\ \ \theta_S \geq \ 15°00'$
9. $\varphi = \frac{\theta_S}{3}\left[\frac{L}{L_S}\right]^2$
10. Exact value of φ by coordinates
$\tan\varphi = \frac{y}{x}$
11. $ST = \frac{y_S}{\sin\theta_S}$
12. $LT = x_S - \left(\frac{y_S}{\tan\theta_S}\right)$
13. $LC = \frac{x_s}{\cos\varphi_S}$
14. $x_S = LC\cos\varphi_S$
15. $y_S = LC\sin\varphi_S$
16. $\theta = \frac{L^2}{L_S^{\ 2}}\theta_s$
17. $x = L\left(1 - \frac{\theta^2}{10} + \frac{\theta^4}{216} - \frac{\theta^6}{9{,}360} + \frac{\theta^8}{685{,}440}\right)^*$
18. $y = L\left(\frac{\theta}{3} - \frac{\theta^3}{42} + \frac{\theta^5}{1320} - \frac{\theta^7}{75{,}600} + \frac{\theta^9}{6{,}894{,}720}\right)^*$

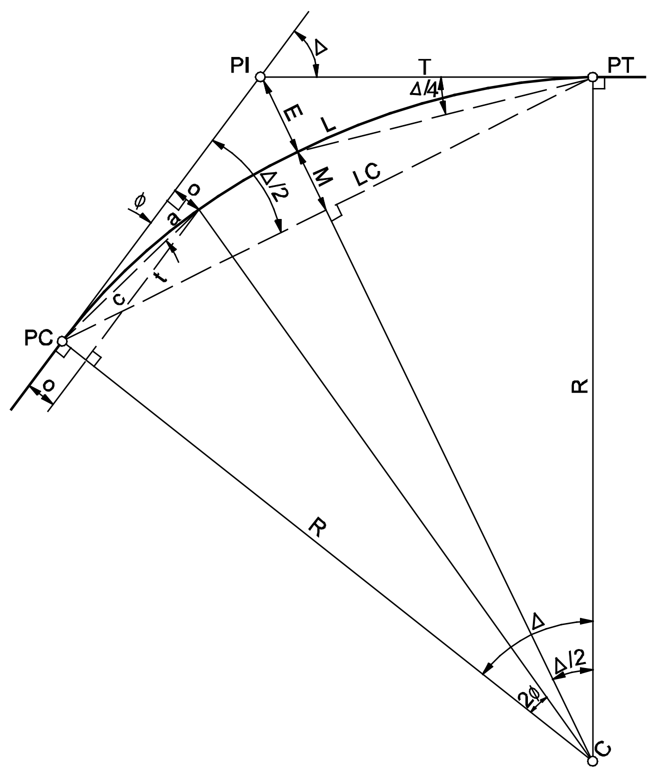
* *θ is in radians for equations 17 and 18 only.*

Note : These equations are based on *Transitions Curves for Highways* by Barnett.

H.2 CIRCULAR CURVES

The following sections provide information on circular curve elements, nomenclature and formulas.

H.2.1 Circular Curve Elements



H.2.2 Circular Curve Nomenclature

Δ	=	Deflection angle, degrees
T	=	Tangent distance, ft. T = distance from *PC* to *PI* or distance from *PI* to *PT*
L	=	Length of curve, ft. L = distance from *PC* to *PT* along curve
R	=	Radius of curvature, ft
E	=	External distance (*PI* to mid-point of curve), ft
C	=	Intersection of radii at center of circular arc
LC	=	Length of long chord (*PC* to *PT*), ft
M	=	Middle ordinate (mid-point of arc to mid-point of long chord), ft
a	=	Length of arc to any point on a curve, ft
c	=	Length of chord from *PC* to any point on curve, ft
φ	=	Deflection angle from tangent to any point on curve, degrees
t	=	Distance along tangent from *PC* to any point on curve, ft
o	=	Tangent offset to any point on curve, ft

H.2.3 Circular Curve Formulas

$$T = R(\tan(\Delta/2)) = R\frac{\sin(\Delta/2)}{\cos(\Delta/2)}$$

$$L = \frac{\Delta}{360}2\pi R$$

$$E = \frac{R}{\cos(\Delta/2)} - R = T\tan(\Delta/4)$$

$$LC = 2R(\sin(\Delta/2)) = 2T(\cos\Delta/2)$$

$$M = R(1 - \cos(\Delta/2)) = E\cos(\Delta/2)$$

$$a = \frac{(200\varphi)(2\pi R)}{100(360)} = \frac{(\varphi)(\pi R)}{90}$$

$$c = 2R\left(\sin\frac{(100)(360a)}{(200)(2\pi R)}\right) = 2R(\sin\frac{90a}{\pi R})$$

$$\varphi = \frac{90a}{(\pi R)}$$

$$\cos\varphi = (R - o)/2R$$

$$t = R\sin 2\varphi = (c)\cos\varphi$$

$$o = (c)\sin\varphi$$

$$o = R - \sqrt{R^2 - t^2}$$

$$o = R - (R\cos 2\varphi)$$

$$o = R(1 - \cos 2\varphi)$$

$$\pi = 3.141592654$$

CIRCULAR CURVE ABBREVIATIONS

PC	=	Point of Curvature (Beginning of Curve)
PT	=	Point of Tangency (End of Curve)
PI	=	Point of Intersection of Tangents
PRC	=	Point of Reverse Curvature
PCC	=	Point of Compound Curvature

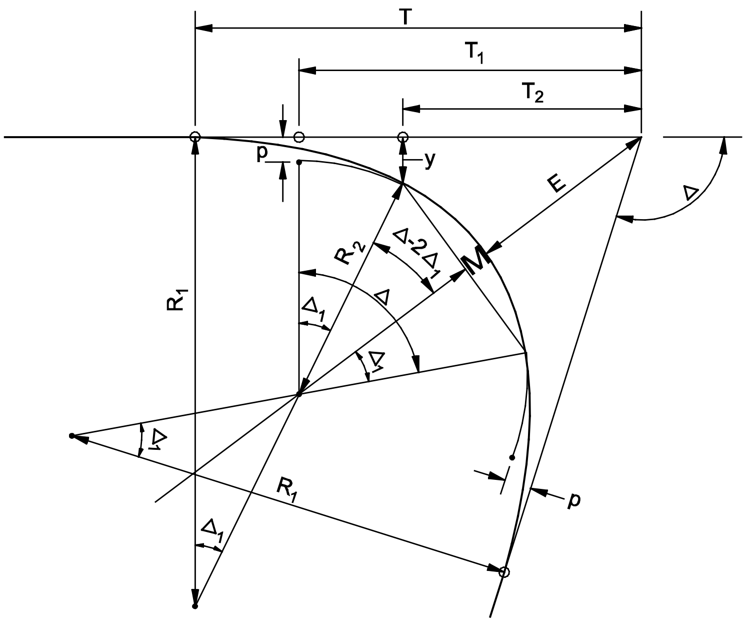
LOCATING THE PC AND PT

Station *PC* = Station *PI* – *T*
Station *PT* = Station *PC* + *L*
Stations are in 100 feet. For example, Sta 13+54.86 means 1,354.86 feet from Sta 0+00.

H.3 COMPOUND CURVES

The following sections provide information on compound curve elements, nomenclature and formulas.

H.3.1 Compound Curve Elements



H.3.2 Compound Curve Formulas

1. $T_1 = (R_2 + p)\tan\dfrac{\Delta}{2}$

2. $\Delta_1 = \cos^{-1}\left[\dfrac{R_1 - R_2 - p}{R_1 - R_2}\right]$

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1$

4. $T_2 = T_1 - R_2 \sin\Delta_1$

5. $E = \dfrac{R_2 + p}{\cos(\Delta/2)} - R_2$

6. $M = R_2 - \lfloor R_2 \cos(\Delta/2 - \Delta_1)\rfloor$

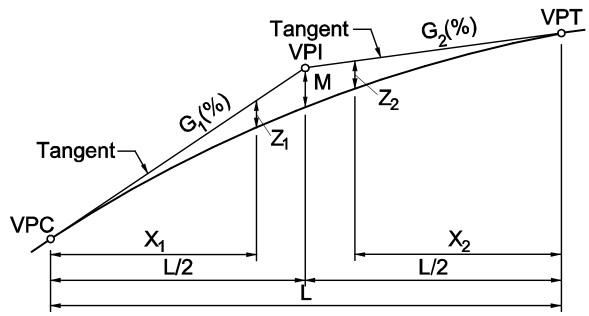
7. $y = (R_2 + p) - R_2 \cos\Delta_1$

Note: "p" is the offset location between the interior curve (extended) to a point where it becomes parallel with the tangent line. See Appendices H.5 and H.6 for other circular curve nomenclature and formulas.

H.4 SYMMETRICAL VERTICAL CURVES

The following sections provide information on symmetrical vertical curve elements, nomenclature and formulas.

H.4.1 Symmetrical Vertical Curve Elements



H.4.2 Symmetrical Vertical Curve Nomenclature

ELEMENT	ABBREVIATION	DEFINITION
Vertical Point of Curvature	*VPC*	The point at which a tangent grade ends and the vertical curve begins.
Vertical Point of Tangency	*VPT*	The point at which the vertical curve ends and the tangent grade begins.
Vertical Point of Intersection	*VPI*	The point where the extension of two tangent grades intersect.
Grade	G_1, G_2	The rate of slope between two adjacent VPI's expressed as a percent. The numerical value for percent of grade is the vertical rise or fall in feet for each 100' of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).
External Distance	M	The vertical distance (offset) between the VPI and the roadway surface along the vertical curve.
Algebraic Difference in Grade	A	The value of *A* is determined by the deflection in percent between two tangent grades (G_2 - G_1).
Length of Vertical Curve	L	The horizontal distance in feet from the VPC to the VPT.
Tangent Elevation	*TAN. ELEV.*	The elevation on the tangent line between the VPC and VPI and the VPI and VPT.
Elevation on Vertical Curve	*CURVE ELEV.*	The elevation of the vertical curve at any given point along the curve.
Horizontal Distance	X	Horizontal distance measured from the *VPC* or *VPT* to any point on the vertical curve, in feet.
Tangent Offset	z	Vertical distance from the tangent line to any point on the vertical curve, in feet.
Low/High Point	X_T	The station at the high point for crest curves or the low point for sag curves.
Symmetrical Curve	—	The *VPI* is located at mid-point between *VPC* and *VPT* stationing.
Unsymmetrical Curve	—	The *VPI* is not located at mid-point between *VPC* and *VPT* stationing.

H.4.3 Symmetrical Vertical Curve Formulas

Note: The variables G_1 and G_2 are percent values.

Elevations of *VPC* and *VPT*:

$$ELEV.\ OF\ VPC = ELEV.\ VPI - G_1\left(\frac{L}{200}\right)$$

$$ELEV.\ OF\ VPT = ELEV.\ VPI + G_2\left(\frac{L}{200}\right)$$

For the elevation of any point "*X*" on the vertical curve:

$$CURVE\ ELEV. = TAN\ \ ELEV. + Z$$

where:

Left of VPI (X_1 measured from VPC):

(a) $TAN.\ ELEV. = VPC\ ELEV. + G_1\left(\frac{X_1}{100}\right)$

(b) $Z_1 = X_1^2\,\frac{(G_2 - G_1)}{200\,L}$

Right of VPI (X_2 measured from VPT):

(a) $TAN\ \ ELEV. = VPT\ ELEV. - G_2\left(\frac{X_2}{100}\right)$

(b) $Z_2 = X_2^2\,\frac{(G_2 - G_1)}{200\,L}$

Calculating high or low point in the vertical curve:

(a) To determine distance "X_T" from *VPC*: $X_T = \frac{L\,G_1}{G_1 - G_2}$

(b) To determine high or low point stationing: $VPC\ \ Sta. + X_T$

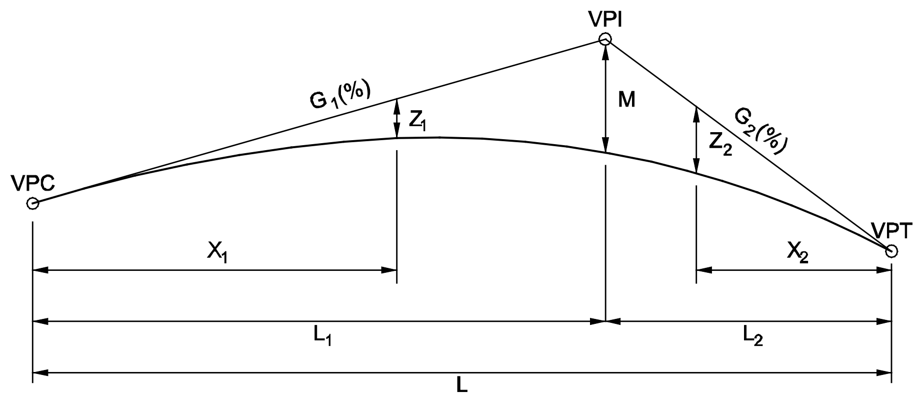
(c) To determine high or low point elevation on the vertical curve:

$$ELEV._{HIGH\ \ OR\ \ LOW\ \ POINT} = ELEV.\ VPC - \frac{L\,G_1^2}{(G_2 - G_1)\,200}$$

H.5 ASYMMETRICAL VERTICAL CURVES

The following sections provide information on asymmetrical vertical curve elements, nomenclature and formulas.

H.5.1 Asymmetrical Vertical Curve Elements



H.5.2 Asymmetrical Vertical Curve Nomenclature

M	=	Offset from the *VPI* to the curve (external distance), feet
Z	=	Any tangent offset, feet
L	=	Horizontal length of vertical curve, feet
L_1	=	Horizontal distance from *VPC* to *VPI*, feet
L_2	=	Horizontal distance from *VPI* to *VPT*, feet
X	=	Horizontal distance from *VPC* or *VPT* to any ordinate "*Z*," feet.
G_1 & G_2	=	Rates of grade, expressed algebraically, percent.

NOTE: ALL EXPRESSIONS TO BE CALCULATED ALGEBRAICALLY (Use algebraic signs of grades; grades in percent.)

H.5.3 Asymmetrical Vertical Curve Formulas

1. Elevations of *VPC* and *VPT*:

$$ELEV.\ \ OF\ \ VPC = ELEV.\ VPI - G_1\left(\frac{L_1}{100}\right)$$

$$ELEV.\ \ OF\ \ VPT = ELEV.\ VPI + G_2\left(\frac{L_2}{100}\right)$$

2. For the elevation of any point "X" on the vertical curve:

$$CURVE\ \ ELEV. = TAN.\ ELEV. + Z$$

Where:

Left of *VPI* (X_1 measured from *VPC*):

(a) $TAN.\ ELEV. = VPC\,ELEV. + G_1\left(\frac{X_1}{100}\right)$

(b) $Z_1 = X_1^2\left(\frac{L_2}{L_1}\right)\left(\frac{G_2 - G_1}{200\ L}\right)$

Right of *VPI* (X_2 measured from *VPT*):

(a) $TAN.\ ELEV. = VPT\,ELEV. - G_2\left(\frac{X_2}{100}\right)$

(b) $Z_2 = X_2^2\left(\frac{L_1}{L_2}\right)\left(\frac{G_2 - G_1}{200\ L}\right)$

3. Calculating High or Low Point on Curve:

Note: Two answers will be determined by solving the equations below. Only one answer is correct. The incorrect answer is where $X_T > L_1$ on the left side of the *VPI* or where $X_T > L_2$ on the right side of the *VPI*.

a. Assume high or low point occurs left of *VPI* to determine the distance, X_T, from *VPC*:

$$X_T = \frac{L_1}{L_2}\left[\frac{G_1 L}{(G_1 - G_2)}\right]$$

Note: Is $X_T > L_1$? If yes, this answer is incorrect and the high or low point is on the right side of the *VPI*. (Go to step "d." to solve for the high or low point elevation.) If no, then this is the correct answer and proceed with steps b. and c. below.)

b. To determine high or low point stationing (where $X_T < L_1$):

$$STA_{\ HIGH\,OR\,LOW\,POINT} = VPC\,STA. + X_T$$

c. To determine high or low point elevation on vertical curve (when $X_T < L_1$):

$$ELEV._{HIGH\ OR\ LOW\ POINT} = ELEV.\ VPC - \frac{L_1}{L_2}\left[\frac{L G_1^2}{(G_2 - G_1)\,200}\right]$$

d. If $X_T > L_1$ from step a., the high or low point occurs right of the *VPI*. Determine the distance X_T from the *VPT*:

$$X_T = \frac{L_2}{L_1}\left[\frac{G_2 L}{(G_2 - G_1)}\right]$$

e. To determine high or low point stationing:

$$STA_{\ HIGH\ OR\ LOW\ POINT} = VPT\ STA. - X_T$$

f. To determine high or low point elevation on the vertical curve:

$$ELEV._{HIGH\ OR\ LOW\ POINT} = ELEV.\ VPT - \frac{L_2}{L_1}\left[\frac{LG_2^2}{(G_2 - G_1)200}\right]$$

Appendix I

Cross Section Elements

Appendix I contains additional design guidance for various cross section elements, which include the following:

- Two-Way, Left-Turn Lanes
- On-Street Parking

I.1 TWO-WAY, LEFT-TURN LANES

Criteria for when a two-way, left-turn lane (TWLTL) is to be used should be coordinated with the MDT Traffic and Safety Bureau. The following provides guidance for where the TWLTL should be considered:

1. **General**. The physical conditions under which a TWLTL should be considered include:
    a. Areas identified by a Traffic Study as having a high number of approaches;
    b. Areas of high-density, commercial development; and/or
    c. Areas with a relatively continuous demand for mid-block left-turns, but where specific approaches do not have a heavy left-turn demand;
2. **Functional Class**. Undivided 2-lane and 4-lane arterials in urban or transitional areas are the most common candidates for the implementation of a TWLTL. Once the TWLTL is used, these are commonly referred to as 3-lane and 5-lane facilities, respectively.
3. **Traffic Volumes.** Traffic volumes are a significant factor in the consideration of a TWLTL. However, if mid-block access is significant, then a TWLTL will be advantageous under any traffic volume level. The design team should coordinate with the Traffic and Safety Bureau to identify the traffic volumes and conditions in which a TWLTL is recommended.
4. **Section Length.** In rural areas, the roadway section length and the number of through lanes are important considerations. For rural and transitional area applications, only consider TWLTL where there are four or more through lanes. The application of short sections of three-lane facilities in rural or transitional areas will be determined on a site-by-site basis.

5. **Crash History.** On high-volume arterials in urban or transitional areas, traffic conflicts often result because of a significant number of mid-block left-turns combined with significant opposing traffic volumes. This may lead to a disproportionate number of mid-block, rear-end, left-turn, and/or sideswipe crashes. When changing from an undivided section, a TWLTL is likely to reduce these types of crashes. The design team should coordinate with the Traffic Engineering Section to review and evaluate the available crash data to determine if unusually high numbers of these crashes are occurring.

I.2 ON-STREET PARKING

The following factors will be evaluated in the decision to retain existing on-street parking or to introduce on-street parking:

1. Crash history or potential safety issues;
2. Impacts to traffic operations of the roadway;
3. Current or predicted demand for parking;
4. Actual needs versus existing number of spaces;
5. Alternative parking options (e.g., off-street parking);
6. Input from local businesses;
7. Impacts on right-of-way;
8. Impacts on bicyclists and pedestrians;
9. Accessibility for pedestrians with disabilities, including pedestrians with vision or mobility impairments.
10. Construction costs; and
11. Projected traffic volumes.

The following summarizes MDT practice on the selection of parking lane type:

1. **General**. Parallel parking is preferred to angle parking.
2. **Existing Angle Parking**. The order of preference for treating existing angle parking is:
    a. Eliminate;
    b. Convert to parallel parking;
    c. Change to back-in angle parking;
    d. Change the angle; or
    e. Leave as is.

    MDT will consult with the local community before selecting an option.

    A local authority may, by ordinance, permit angle parking on a roadway; however, angle parking will not be permitted on any Federal-aid or State highway unless MDT determines that the roadway is of sufficient width to permit angle parking and it does not negatively impact the traffic operations and/or safety of the roadway.

3. **New Parking**. Where on-street parking will be introduced, the design team should:
    a. Consider the various types of on-street parking options;
    b. Coordinate with the Traffic and Safety Bureau to understand the traffic operations and safety considerations of the roadway;
    c. Gather stakeholder input to understand the needs of the community; and,
    d. Develop a cross section that serves the function of the roadway and balances the needs of all users.

Appendix J

Supplemental Quantity Summaries Information

Appendix J contains supplemental information associated with Chapter 13: Quantity Summaries, which include the following:

- Quantity Rounding Criteria
- Basis of Plan Quantities

J.1 QUANTITY ROUNDING CRITERIA

The following table provides a summary of rounding criteria for various frames. Chapter 13 provides additional information on Quantities Summaries.

Item	Measured Unit	Rounding Criteria
MISCELLANEOUS ITEMS FRAME		
Miscellaneous Items	cubic yard, cy square yard, sy linear foot, lnft hour, hr lump sum each, ea	1
FINISH GRADE CONTROL FRAME		
Finish Grade Control	course-foot, crft	Up to nearest 50 foot
CLEARING & GRUBBING FRAME		
Clearing and Grubbing	acre or lump sum	0.1 1
REMOVE TREES FRAME		
Remove Trees	each, ea	1
REMOVE STRUCTURE FRAME		
Remove Structure	lump sum or each, ea	1
BITUMINOUS PAVEMENT REMOVAL FRAME		
Remove Bituminous Pavement	square yard, sy	1

Item	Measured Unit	Rounding Criteria
GRADING FRAME		
Unclassified Excavation Excavation Street Excavation Unclassified Borrow Excavation Excess Excavation Embankment + Embankment in Place	cubic yard, cy	1
ADDITIONAL GRADING FRAME		
Unclassified Excavation Excavation Street Excavation Embankment + Embankment in Place Additional Unclassified Excavation Additional Embankment in Place	cubic yard, cy	1 nearest 5 if not incl. in earthwork run, (min. 5)
SPECIAL BORROW FRAME		
Special Borrow – Excavation Special Borrow Neat Line	cubic yard, cy	1
SUBEXCAVATION FRAME		
Unclassified Excavation Street Excavation Embankment in Place Special Borrow Neat Line	cubic yard, cy	1
DIGOUT FRAME		
Digout Excavation Special Borrow Neat Line	cubic yard, cy	1
Geotextile	square yard, sy	1
MUCK EXCAVATION FRAME		
Muck Excavation Special Borrow Neat Line	cubic yard, cy	1
EMBANKMENT FOUNDATION TREATMENT FRAME		
Special Borrow Neat Line	cubic yard, cy	1
Geotextile	square yard, sy	1
DRILL PRESPLIT HOLES FRAME		
Drill Presplit Holes	linear foot, lnft	1
SCALING FRAME		
Hours	hour, hr	1
Cubic Yards (for information only)	cubic yard, cy	1
DETOUR FRAME		
Detour - Construct, Maintain & Remove Detour - Construct & Maintain	lump sum or each, ea	1
Detour - Maintain & Remove Detour - Maintain	lump sum	1
EQUIPMENT FRAME		
Motor Grader Dozer Miscellaneous Equipment	hour, hr	1

Item	Measured Unit	Rounding Criteria
OBLITERATE ROADWAY FRAME		
Obliterate Roadway	stations, sta. (100 ft)	1
Unclassified Excavation (for information only) Embankment + (for information only)	cubic yard, cy	1
BRIDGE END BACKFILL FRAME		
Bridge End Backfill	cubic yard, cy	1
Geotextile	square yard, sy	1
PULVERIZATION FRAME		
Pavement Pulverization	square yard, sy	1
SURFACING & ADDITIONAL SURFACING FRAMES		
Distance *	linear foot, lnft	0.01
Hydrated Lime Mineral Filler - CIR Plant Mix Surfacing Microsurfacing Aggregate	ton	1
Cover Blotter Material Cold Recycled Plant Mix Aggregate Treatment Cement Treated Pulverized Base Portland Cement Concrete Pavement	square yard, sy	1
Crushed Aggregate Course Special Borrow Neat Line Crushed Top Surfacing Shoulder Gravel Traffic Gravel	cubic yard, cy or ton	1
Non-frost Susceptible Backfill Cement Treated Base	cubic yard, cy	1
Asphalt Cement Seal Curing Seal Recycling Agent CIR-EE Microsurfacing Emulsion	ton	0.1
Tack Fog Seal	gallon, gal	1
RUMBLE STRIPS FRAME		
Rumble Strips	mile, mi	0.1
Fog Seal (for information only)	gallon, gal	1
CRACK SEALING FRAME		
Crack Sealing	pound, lb	1
Crack Sealing (for information only)	linear foot, lnft	1
COLD MILLING FRAME		
Cold Milling	square yard, sy	1
CRACK & SEAT FRAME		
Crack and Seat	square yard, sy	1
* Where existing stationing is utilized, the dimensions may only be available to the nearest 0.1’.		

Item	Measured Unit	Rounding Criteria
RAIL FRAME		
Hand Rail Pedestrian Rail	linear foot, lnft	0.1
WATER LINE FRAME		
Adjust Water Main / Service Line Water Service Valve Connection Pipe Plug Fire Hydrant	each, ea	1
Pipe – PVC Pressure Water Steel Casing Special Installation of Pipe	foot, ft	1
Ductile Iron Fittings	pound, lb	1
Controlled Low Strength Material	cubic yard, cy	1
CULVERT FRAME (Option, No Option, Approach and Recap)		
Length of Pipe	foot, ft	2 6 for RCB
Relay Pipe Culvert	foot, ft	2
Clean Culvert Pipe	foot, ft	1
Height of Cover Remove Pipe Culvert	foot, ft	0.1
Foundation Material Bedding / Granular Bedding Material Special Backfill Fill and Abandon Pipe	cubic yard, cy	1
Concrete Class General	cubic yard, cy	0.1
Plug Ends and Abandon Pipe	each, ea	1
Geotextile	square yard, sy	1
STOCKPASS FRAME		
Length of Pipe	foot, ft	2
Plant Mix Surfacing	ton	1
Crushed Aggregate Course Foundation Material Granular Bedding Material Special Backfill	cubic yard, cy	1
Concrete Class General	cubic yard, cy	0.1
Geotextile	square yard, sy	1
Height of Cover	foot, ft	0.1
UNDERDRAIN FRAME		
Length of Pipe	foot, ft	2
Geotextile	square yard, sy	1
Trench Excavation (not a pay item)	cubic yard, cy	5
Filter Material	cubic yard, cy	0.1

Item	Measured Unit	Rounding Criteria
STORM DRAIN FRAME		
Pipe Lengths Slotted Drain	foot, ft	0.1
Manhole Manhole and Inlet (Combo - Drop / Curb) Inlet (Drop / Curb) Remove Inlet / Manhole Reset Inlet / Manhole	each, ea	1
Granular Bedding Material Fill and Abandon Pipe	cubic yard, cy	1
Trench Excavation (not a pay item)	cubic yard, cy	5
EMBANKMENT PROTECTORS FRAME		
Embankment Protector – 18 inches	foot, ft	2
Concrete Curb	foot, ft	0.1
Bank Protection	cubic yard, cy	0.1
MEDIAN INLETS FRAME		
Median Inlet Adjust Median Inlet	each, ea	1
GUARDRAIL FRAME		
New Metal Guardrail Intersecting Roadway Terminal Section	foot, ft	12.5
Box Beam Guardrail	foot, ft	18
Remove Guardrail Cable Guardrail	foot, ft	0.1
Bridge Approach Section Box Beam Bridge Approach Section Optional Terminal Section Optional Box Beam Terminal Section Box Beam Departure Terminal Section One-Way Departure Terminal Section Cable Guardrail Terminal Section Guardrail End Section Widening	each, ea	1
TEMPORARY GUARDRAIL FRAME		
Temporary Metal Guardrail	foot, ft	12.5
Temporary Concrete Barrier Rail	each, ea (10-foot increment)	1
Temporary Optional Terminal Section Temporary Bridge Approach Section Temporary Impact Attenuator	each, ea	1

Item	Measured Unit	Rounding Criteria
CONCRETE BARRIER RAIL FRAME		
Remove Concrete Barrier Rail Concrete Barrier Rail Tall Concrete Barrier Rail One-Way Depart. Conc. Barrier Sect. Concrete Barrier Rail Transition Reset Concrete Barrier Rail	each, ea (10-foot increment)	1
Impact Attenuator Remove Impact Attenuator	each, ea	1
FENCING FRAME		
Fence Types Remove / Reset Fence	foot, ft	1
Panels Deadman New Wood or Metal Posts	each, ea	1
Gates	foot, ft	2
SIDEWALK FRAME		
Concrete Sidewalk Detectable Warning Devices Remove Sidewalk	square yard, sy	0.1
CURB FRAME		
Concrete Curb and Gutter Remove Curb and Gutter Concrete Curb	foot, ft	0.1
Concrete Valley Gutter	square yard, sy	0.1
MEDIAN CONCRETE CURB FRAME		
Concrete	square yard, sy	0.1
Median Curb Remove Median Curb	foot, ft	0.1
TOPSOIL & SEEDING / REVEGETATION FRAMES		
Salvaging and Placing	cubic yard, cy	1
Seed Fertilizer Condition Seedbed Mulch / Mulch-Compost / Compost Revegetation	acre	0.1
Revegetation	lump sum	1
PERMANENT EROSION CONTROL FRAME		
Random Riprap	cubic yard, cy	0.1
Wetland Soil - Salvage and Place Streambed Material Crushed Aggregate Course	cubic yard, cy	1
Geotextile Turf Reinforcement Mat Erosion Control Blanket Coir Erosion Control Net	square yard, sy	1

Item	Measured Unit	Rounding Criteria
LANDSCAPING FRAME		
Landscaping	lump sum	1
WETLAND SITE FRAME		
Wetland Site	lump sum	1
CATTLE GUARD FRAME		
Cattle Guard Reset Cattle Guard Remove Cattle Guard	each, ea	1
RANDOM RIPRAP & RIPRAP REVEGETATION FRAMES		
Random Riprap	cubic yard, cy	0.1
Geotextile	square yard, sy	1
Riprap Revegetation	square yard, sy	1
CONCRETE DRAINAGE CHUTES FRAME		
Concrete Class General	cubic yard, cy	0.1
CONCRETE DITCH FRAME		
Concrete Ditch	foot, ft	0.1
Special Backfill	cubic yard, cy	1
Drain Aggregate Bank Protection	cubic yard, cy	0.1
Geomembrane	square yard, sy	1
GABIONS FRAME		
Gabion Structure Gabion Mattress	cubic yard, cy	1
RETAINING WALL FRAME		
Retaining Wall	linear foot, lnft or sq yard, sy	0.1
Design, Const. MSE Walls Soil Nail Retaining Wall Design, Const. Gravity Ret. Wall	square yard, sy	1
IRRIGATION STRUCTURES FRAME		
Concrete Class General Random Riprap	cubic yard, cy	0.1
Geotextile	square yard, sy	1
Irrigation Canal Gate Slidegate Gate Valve Trash Guard Canal Check Structure Remove Irrigation Structure	each, ea	1
TRAFFIC CONTROL FRAME		
Traffic Control Ramp Crossover Traffic Control Crossover	each, ea	1
Traffic Control Two-Way Traffic	mile, mi	0.1

Item	Measured Unit	Rounding Criteria
MEDIAN CROSSOVER FRAME		
Crossover – Const., Maintain & Remove Crossover – Const., Maintain & Close Crossover – Const. & Maintain Crossover – Maintain Crossover – Maintain & Close Crossover – Maintain & Remove Ramp Crossover Remove Crossover Crossover Reclamation	each, ea	1
PAVEMENT MARKING FRAME		
Remove Pavement Markings	foot, ft	1
Striping - Paint / Epoxy Words and Symbols – Paint / Epoxy Curb Markings – Paint / Epoxy	gallon, gal	1
Thermoplastic Treatment	lump sum	1
Temporary Striping	mile, mi	0.1
Final Sweep and Broom	course mile, crmi	0.1
MANHOLES IN PLACE FRAME		
Adjust Manhole	each, ea	1
WATER VALVE BOXES FRAME		
Adjust Water Valve Box Reset Water Vale Box	each, ea	1
EDGE DRAIN FRAME		
Edge Drain	linear foot, lnft	1
Side Drain	each, ea	1
MAILBOX FRAME		
Mailbox	each, ea	1

J.2 BASIS OF PLAN QUANTITIES

The following table provides a summary of basis of plan quantities. The quantities are for estimating purposes only.

COMP. AGGREGATE WEIGHT	= 3700 LBS. PER CUBIC YARD (1)
COMP. WEIGHT OF PL. MIX BIT. SURF.	= 3855 LBS. PER CUBIC YARD (2)
ASPHALT CEMENT - GRADE S - 3/8" AGG.	= 6.2% OF PL.MIX BIT.SURF.
ASPHALT CEMENT - GRADE S - 1/2" AGG.	= 5.8% OF PL.MIX BIT.SURF. (3), (4)
ASPHALT CEMENT - GRADE S - 3/4" AGG.	= 5.4% OF PL.MIX BIT.SURF. (3)
HYDRATED LIME	= 1.4% OF PL.MIX BIT.SURF.
ASPHALT CEMENT	= 3.0% OF RECYCLED PL.MIX (50% RAP) (5)
BITUMINOUS MATERIAL	= 8.5 LBS. PER GAL.
EMULSIFIED ASPHALT - TACK (All other surfaces)	= 0.05 GAL. PER SQ.YARD (UNDILUTED)
EMULSIFIED ASPHALT - TACK (concrete surfaces)	= 0.10 GAL. PER SQ.YARD (UNDILUTED)
EMULSIFIED ASPHALT - FOG SEAL (seal and cover)	= 0.075 GAL. PER SQ.YARD (UNDILUTED)
EMULSIFIED ASPHALT - FOG SEAL (rumble strips)	= 0.10 GAL. PER SQ.YARD (UNDILUTED)
SEAL	= 0.42 GAL. PER SQ.YARD
COVER	= 25 LBS. PER SQ.YARD
CURING SEAL	= 0.2 GAL. PER SQ.YARD
COMP. WEIGHT OF CTB	= 3620 LBS. PER CUBIC YARD
BLOTTER	= 15 LBS. PER SQ.YARD
PORTLAND CEMENT	= 5.0% PULV. CTB - DRY WT. (6)

(1) 3,750 lbs per cu. yd. – Billings District, except Lewistown area and Eastern Part of District.
3,625 lbs per cu. yd. – Lewistown area and Eastern part of Billings District.

(2) 4,167 lbs per cu. yd. – Billings District

(3) Obtain project specific A/C rates from Surfacing Design. If commercial mix is specified or project specific rates are not available, use the rate shown.

(4) 1/2” is the max PMS AGG. size for use in Missoula District.

(5) Applicable to projects with recycled asphalt pavement (RAP)

(6) Indicate Portland Cement rate only if measured for payment. Obtain project specific rate from Surfacing Design unit.

Appendix K

Example Calculations

Appendix K includes example calculations for the Road Design Manual. The examples are numbered to correspond with the associated chapter material, as described below.

- Sight Distance (Chapter 2)
- Horizontal Alignment (Chapter 3)
- Vertical Alignment (Chapter 4)
- Roadside Safety (Chapter 9)
- Quantity Summaries (Chapter 13)

Sight Distance Example Calculations

Example 2-1: Horizontal Sight Distance – Middle Ordinate

Given: Design Speed = 60 mph
R = 1,400 feet

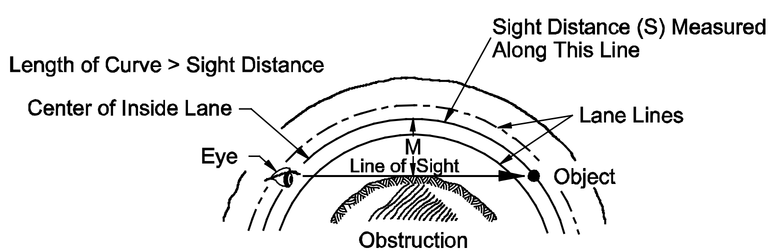
Problem: Determine the horizontal clearance requirements for the horizontal curve using the desirable stopping sight distance (*SSD*) value.

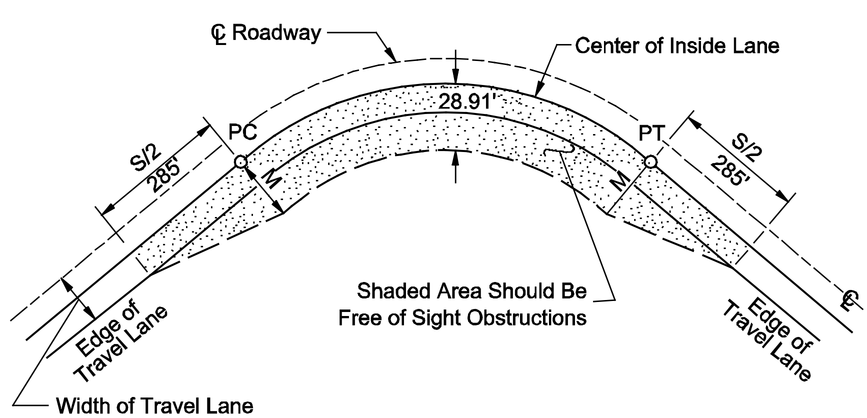
Solution: Chapter 2, Exhibit 2-1 yields a *SSD* = 570′. Using Appendix F, Equation F.2-1 for horizontal clearance:

$$M = R\left(1 - \cos\left(\frac{90° \cdot S}{\pi \cdot R}\right)\right)$$

$$M = 1400\left(1 - \cos\left(\frac{(90°)(570)}{(\pi)(1400)}\right)\right) = 28.91'$$

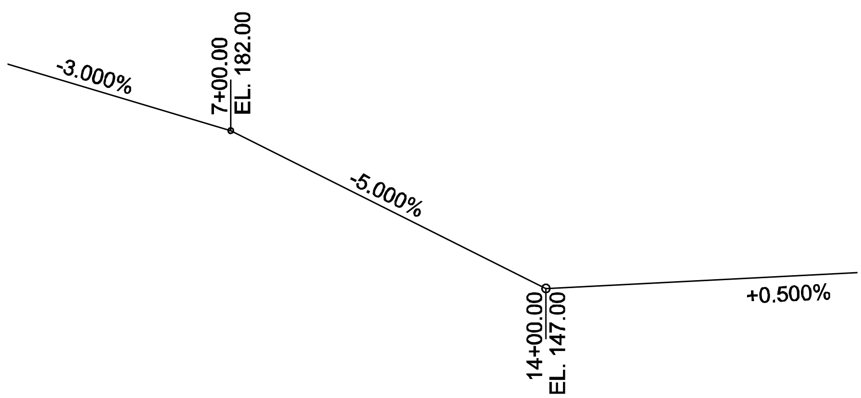
The exhibit below illustrates the horizontal clearance requirements for the entering and exiting portion of the horizontal curve.





Example 2-2: Stopping Sight Distance with Vertical Curves

Given: The grade line for a 60-mph design speed, two-lane, two-way rural roadway is shown below. Give consideration to the effect of grades on *SSD*.



Problem: Determine the appropriate profile that meets minimum stopping sight distance, as well as consider passing sight distance for additional refinement.

Solution:

1. Since the grades are 3 percent and greater, determine stopping sight distance adjusted for downgrades. The 5-percent grade is the maximum of the downgrades, and will be used for calculating *SSD*. Using Chapter 2, Equation 2.8-3:

$$SSD_{\text{Downgrades}} = 1.47Vt + \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) - G\right]}$$

where:

SSD = stopping sight distance, feet.

V = design speed, mph

t = brake reaction time, 2.5 seconds

a = deceleration rate, 11.2 foot per second squared

G = gradient, feet/feet

$$SSD_{-5\%} = 1.47 \times 60 \times 2.5 + \frac{60^2}{30[(11.2 \div 32.2) - .05]} = 623.4\text{, Round} \Rightarrow \underline{624'}$$

2. Second, calculate the minimum length for the crest curve for the calculated *SSD* using Equation 4.4-1:

$$L = \frac{AS^2}{200(\sqrt{h_1} + \sqrt{h_2})^2}$$

Where:

L = length of vertical curve, feet

A = algebraic difference between the two tangent grades, percent

S = sight distance, feet

h_1 = height of eye above road surface, feet

h_2 = height of object above road surface, feet

$$L = \frac{AS^2}{200 \times \left(\sqrt{h_1} + \sqrt{h_2}\right)^2} = \frac{2 \times 624^2}{2158} = 360.87'$$

3. Since this length is less than the *SSD*, Equation 4.4-2 can be used :

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

Where:

L = length of vertical curve, feet

A = algebraic difference between the two tangent grades, percent

S = sight distance, feet

h_1 = height of eye above road surface, feet

h_2= height of object above road surface, feet

$$L = 2S - \frac{200 \times \left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A} = 2 \times 624 - (2158 \div 2) = 169'$$

The minimum curve length providing *SSD* is 169 feet, however the minimum curve length based on $L_{min} = 3V$ would be 180 feet.

4. Prior to finalizing the crest curve length, we'll determine the needed length for the sag curve based on *SSD*:

   Calculate the minimum length for the sag curve using Equation 4.4-7:

$$L = \frac{AS^2}{200h_3 + 3.5S}$$

Where:

L = length of vertical curve, feet

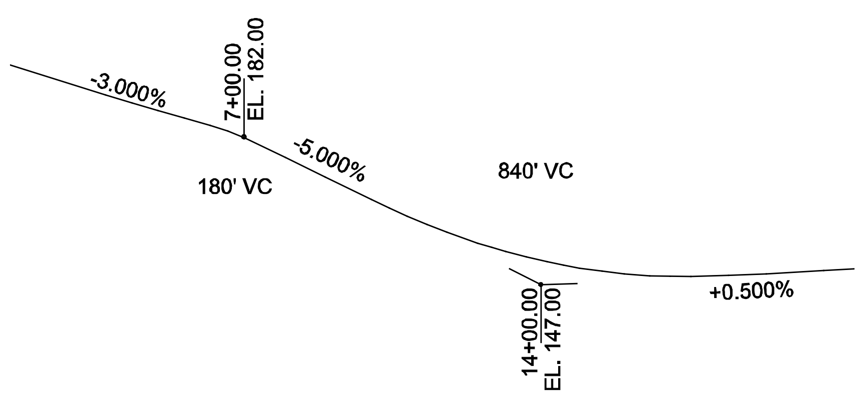
A = algebraic difference between the two tangent grades, percent

S = sight distance, feet

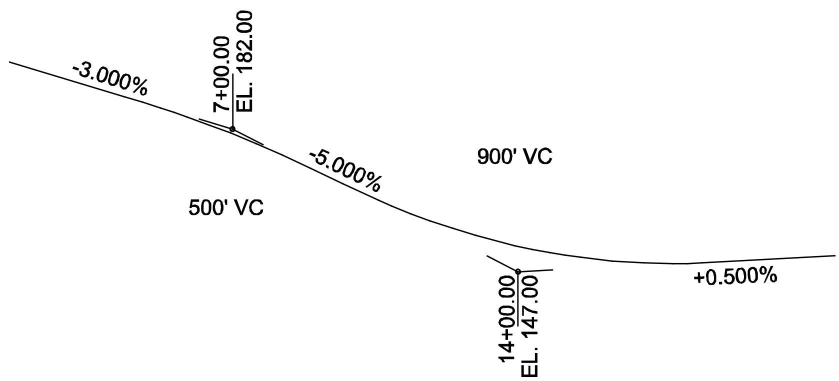
h_3 = height of headlights above pavement surface, feet

$$L = \frac{AS^2}{200 \times h_3 + 3.5S} = \frac{5.5 \times 624^2}{200 \times 2 + (3.5 \times 624)} = 828.78'$$

For this example, both curves can be designed to provide *SSD* adjusted for the 5 percent downgrade, using a 180-foot long crest and 840-foot sag curves (lengths rounded up for design), without curve overlap.



Additional Discussion: Rather than using the minimum lengths of curve calculated, consideration should be given to increasing the curve lengths to provide additional sight distance and reducing the length of the 5 percent grade. Using the curve lengths shown below, the 5 percent grade occurs at station 9+50 only, and reduces from that point in each direction.



Using equation 4.4-2 with the 500-foot crest length and solving for *S*, stopping sight and passing sight distances provided are 789.5 feet and 950 feet, respectively. Since both are influenced by the adjacent sag curve, graphical analysis shows that actual minimum sight distances provided are 825 feet *SSD* and 1080 feet *PSD*, meeting the criteria for 60 mph.

Since the sag curve is longer than the stopping sight distance provided, the minimum *SSD* provided can be found using equation 4.4-7, and is 670 feet whenever the vehicle and 1 degree rise in headlight are on the sag.

It is worth noting that the downgrade of the roadway during the braking operation is much lower than the 5 percent used to calculate required stopping sight distance for the sag curve. It varies from -3.65 to -.9 percent at the steepest point that *SSD* is at its minimum for the curve shown above. In this respect, using the *SSD* adjusted for grades is significantly more conservative when applied to sag curves compared to crest curves, and may warrant closer analysis for situations where site constraints or impacts limit curve length.

Example 2-3: Combination of Vertical and Horizontal Curves

Given: **Horizontal curve data**

PI = 50+00.00
Δ = 27°15′18″ (RT)
R = 3,000 feet
S = 4.0%
Design speed = 60 mph
Two-lane, two-way roadway with 12-foot travel lanes, 4-foot shoulders
Guardrail on the inside shoulder with face of rail at edge of shoulder
Guardrail post height = 30 inches

Symmetrical vertical curve data

G1 = +2.00%
G2 = -2.50%
VPI elev. = 1,308.00'
VPI station = 49+00.00
L = 2,000'

Problem: Graphically determine if the combination of horizontal and vertical curves provides Stopping Sight Distance (*SSD*) using CAD software.

Solution:

1. Draw the horizontal curve showing travel lanes, center of travel lanes, shoulders and guardrail.

2. Determine *SSD* for 60 mph from table in Exhibit 2-1. (*SSD* = 570')

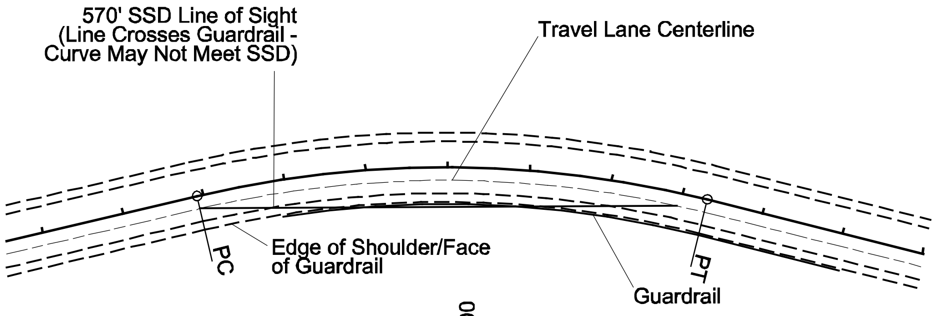
3. Draw a sight line the length of the *SSD* as a chord across the curve from the center of near travel lane to the center of near travel lane. If the line crosses the guardrail the curve may not meet *SSD*.

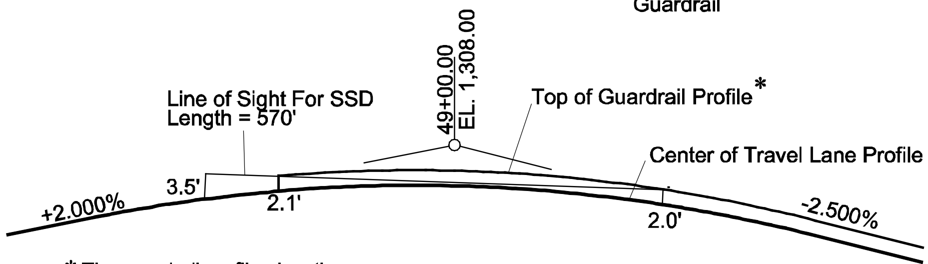
4. If the horizontal curve appears to provide a *SSD* line of sight, check the vertical profile for meeting *SSD* (step 5). If it appears that the curve does not meet the *SSD*, then graphically check the roadway profile with the guardrail profile shown to determine if the line of sight clears the top of the guardrail (step 6).

5. To graphically check the *SSD* of the roadway profile:
   a. Draw the profile for the area of the horizontal curve which in this case includes a crest vertical curve.
   b. Draw an element, to the same scale the profile was drawn, representing the *SSD*.
   c. Draw the element with a horizontal line of sight line the length of the *SSD* and with a vertical leg under each end, 3.5' high on the driver's eye height side and 2.0' high on the object height side.
   d. Place the element on the profile with the legs touching the profile.
   e. Move the element along the profile through the vertical curve while keeping the legs on the profile.
   f. If at any point the profile line crosses the line of sight part of the element, the curve does not meet *SSD*.

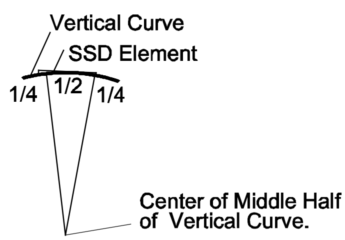
6. To graphically check the *SSD* on the roadway profile with the guardrail, draw the profile for the area of the horizontal curve which in this case includes a crest vertical curve. Draw the top of guardrail profile at the correct height above the roadway profile.
   a. The guardrail profile elevation = roadway profile elevation + (guardrail post height - (distance from the face of rail to the center of the travel lane x the roadway cross slope rate)).
   b. Draw an element, to the same scale the profile was drawn, representing the *SSD*.
   c. Draw the element with a horizontal line of sight line the length of the *SSD* and with a vertical leg under each end, 3.5' high on the driver's eye height side and 2.0' high on the object height side.
   d. Place the element on the roadway profile with the legs touching the profile.
   e. Move the element along the roadway profile through the vertical curve.
   f. If at any point the guardrail profile line crosses the horizontal part of the element, the vertical curve does not meet *SSD*.

This method can be used to check *SSD* and passing sight distance (*PSD*) on any combination of horizontal/vertical curves with possible sight restrictions caused by backslopes, rocks, fences, buildings, crops, etc. It can also be used to check *SSD* and *PSD* on multiple short vertical curves with little or no tangent grade between them.



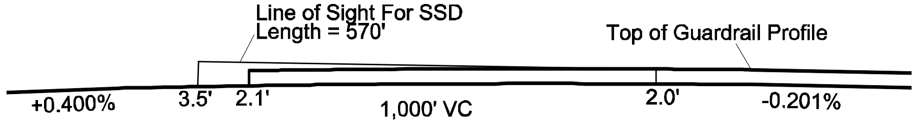


* The guardrail profile elevation =
travel lane centerline profile elevation + [guardrail post height (2.5') - distance from the face of rail to the center of the travel lane (10') x the cross slope rate (0.4)] =
travel lane centerline profile elevation + [2.5'- (10' x .04)]



To move the SSD element through the vertical curve, rotate the element about the center of middle half of the vertical curve. Some tweaking of the element may be required near the edges of the vertical curve.

The line of sight for the *SSD* is crossed by both the face of guardrail horizontal alignment and by the top of guardrail profile. Therefore, this combination of vertical curve, horizontal curve, and guardrail offset does not meet *SSD*. The design team may consider widening the shoulder, eliminating the roadside hazard that is requiring guardrail, using a larger radius horizontal curve, flattening the grades, and/or using a longer vertical curve. The exhibit shown below illustrates an example of modifications required of the profile to meet the *SSD*. It appears that increasing the horizontal curve radius or increasing the shoulder width/guardrail offset may be more practical ways to achieve the required *SSD* in this case.

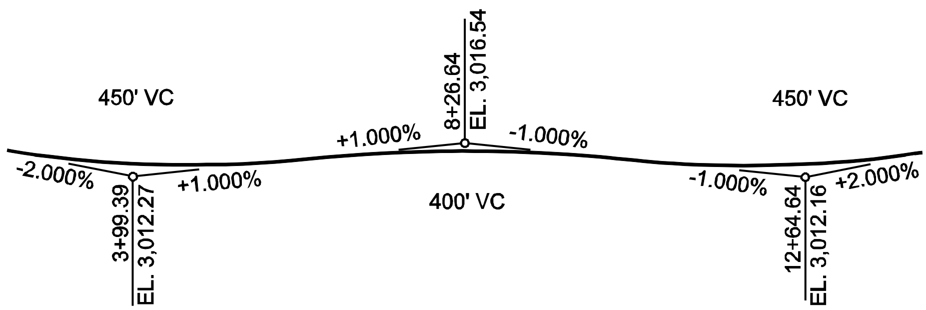


Example Drawings Not To Scale Or Proportional.

Example 2-4: Passing Sight Distance

Given: Refer to the below crest vertical curve for given information.

Problem: For a design speed of 60 mph on a rural, two-lane, two-way highway, does the following crest vertical curve meet minimum passing sight distance (*PSD*)? Give consideration to the multiple curves.



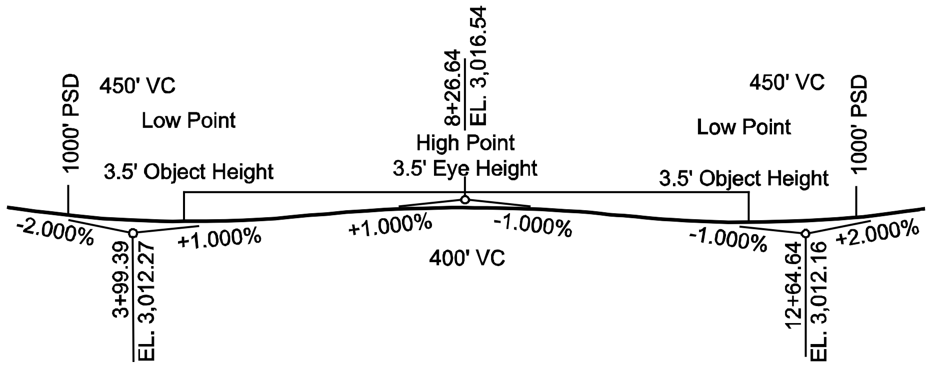
Solution:

1. From Exhibit 2-10, the minimum passing sight distance for a design speed of 60 mph for the above crest vertical curve is 1,000′. Using the passing sight distance of 1,000′ to calculate the length of vertical curve when S is greater than L, use Equation 4.4-2:

$$L = 2S - \frac{200 \times \left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

The length of vertical curve required would be 600′. From inspection, the crest vertical curve (Length = 400′) is less than the minimum required crest vertical curve (Length = 600′) when designing for passing sight distance. If this crest vertical curve was connected by lengthy tangents sections extending at +1.0% and -1.0%, instead of short tangent sections connecting to sag vertical curves as shown above, then this crest vertical curve would not meet the minimum passing sight distance for 60 mph design speed.

Consideration must be given for passing sight distance across multiple curves when they are connected by short tangents. If you plot the height of eye (3.5′) at the high point of the crest vertical curve and the height of object (3.5′) at the low point of both sag vertical curves, you can graphically determine if this crest vertical curve meets minimum passing sight distance.



Refer to the above diagram for plotting sight distance across the crest vertical curve. Plotting the low points of both sag vertical curves (at 3.5 foot object height) and the high point of the crest vertical curve (at 3.5 foot eye height), you can visually see that the sight distance is sufficient. If passing sight distance is sufficient at the low points, then it will also be sufficient at 1,000 feet.

In conclusion, the crest vertical curve does meet the minimum requirements for 1,000 feet passing sight distance. If consideration was not given to passing sight distance across multiple curves, then this crest vertical curve would not have met the minimum passing sight distance.

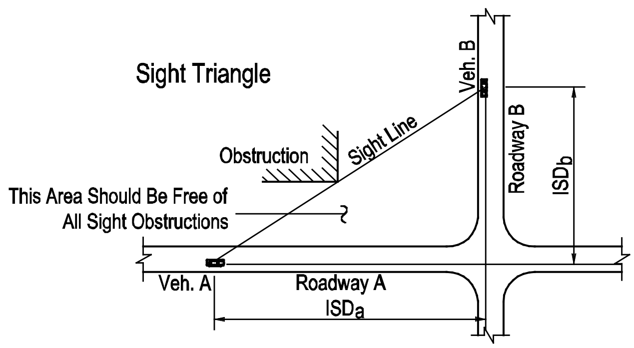
Example 2-5: Intersection Sight Distance (*ISD*) – No Traffic Control

Given: No traffic control intersection.

Design speed: 35 mph (Roadway A)

Design speed: 25 mph (Roadway B)

Note: This exhibit is not applicable for State highways.



Design Speed (mph)	15	20	25	30	35	40	45	50
*Intersection Sight Distance (ft)	70	90	115	140	165	195	220	245

Note: For approach grades greater than 3%, multiply the sight distance values in this table by the appropriate adjustment factor from Appendix F, Exhibit F-8. The grade adjustment is based on the approach roadway grade only.

Problem: Determine legs of sight triangle.

Solution: From the table shown above:

$ISD_a = 165'$

$ISD_b = 115'$

Example 2-6: Intersection Sight Distance – Stop Controlled

Given: Minor road intersects a 4-lane highway with a two-way, left-turn lane (TWLTL).
Minor road is stop controlled.
Design speed of the major highway is 50 mph.
All travel lane widths are 12 feet.
The TWLTL width is 14 feet.
Trucks are not a concern.

Problem: Determine the intersection sight distance (*ISD*) to the left and right from the minor road.

Solution: The following steps will apply:

1. For the vehicle turning right from the minor road, the intersection sight distance (*ISD*) to the left can be determined directly from Appendix F, Exhibit F-11. For the 50-mph design speed, the *ISD* to the left is 480 feet.

2. For the vehicle turning left, the *ISD* must reflect the additional time required to cross the additional lanes. The following will apply:
   a. First, determine the extra width required by the one additional travel lane and the TWLTL and divide this number by 12 feet:

      $(12 + 14) \div 12 = 2.2$ lanes

   b. Next, multiply the number of lanes by 0.5 seconds to determine the additional time required:

      (2.2 lanes) x (0.5 sec/lane) = 1.1 seconds

   c. Add the additional time to the basic gap time of 7.5 seconds and insert this value into Appendix F, Equation F.3-1:

      $ISD = (1.47) \times (50) \times (7.5 + 1.1) = 632'$

      Provide an *ISD* of 635′ to the right for the left-turning vehicle.

3. Check the crossing vehicle, as discussed in Appendix F, Section F.3.2.2. The following will apply:
   a. First determine the extra width required by the two additional travel lanes and the TWLTL and divide this number by 12 feet:

      $$\frac{(12+12+14)}{12} = 3.2 \text{ lanes}$$

b. Next, multiply the number of lanes by 0.5 seconds to determine the additional time required:

(3.2 lanes)(0.5 sec/lane) = 1.6 seconds

c. Add the additional time to the basic gap time of 6.5 seconds and insert this value into Appendix F, Equation F.3-1:

ISD = (1.47) (50) (6.5 + 1.6) = 595′

The 595′ for the crossing maneuver is less than the 635′ required for the left-turning vehicle and, therefore, is not the critical maneuver.

Example 2-7: Decision Sight Distance

Given: A rural two-lane, two-way, level roadway with a design speed of 60 mph.

Problem: Determine the associated avoidance maneuvers for the given roadway and determine the decision sight distances for each of the avoidance maneuvers.

Solution: From the footnotes of Exhibit 2-12: This is a rural facility, the two avoidance maneuvers that address rural roads are A and C.

From Exhibit 2-12: Using the design speed of 60 mph, the decision sight distances for a rural roadway are:

Avoidance Maneuver A: 610 feet
Avoidance Maneuver C: 990 feet

Horizontal Alignment Example Calculations

Example 3-1: Spiral Curve

Given: Rural Two-Lane, Two-Way Highway
Design Speed = 70 mph
Δ = 15°00'00"
(Master) PI Station = 243+18.72
R_c = 3,000 feet
e_{max} = 8%
Refer to Appendix H.1.1 for a diagram of the different elements of a spiral curve and Appendix H.1.2 for the associated definitions for these different elements.

Problem: If a spiral curve is warranted, determine the curve data for the spiral curve.

Solution: The following steps apply:

1. From Chapter 3, Section 3.2.1, a spiral curve is warranted on a rural State highway where the superelevation, *e,* is greater than or equal to 7%. From Chapter 3, Exhibit 3-5, *e* is 7% for *V* = 70 mph and R_c = 3,000 feet, therefore, use a spiral curve.

2. The length of the spiral curve (L_s) is set equal to the superelevation runoff (*L*) length. From Chapter 3, Exhibit 3-5, *L* = 210' for *V* = 70 mph and *R* = 3,000 feet, therefore, L_s = 210 feet.

3. Calculate the curve parameters by using the spiral curve formulas provided in Appendix H.1.3:

    1. $\theta_S = (L_s / R_C)(90/\pi) = (210/3000)(90/\pi)$
       $\theta_S = 2.00535...°$
       $\theta_S = 2°00'19"$ (rounded value)
    2. $\Delta_C = \Delta - 2\theta_S = (15°00'00") - 2(2°00'19")$
       $\Delta_C = 10°59'22" = 10.9894...°$
       (Note: Rounding to the nearest second requires decimal degrees to the nearest 0.0001.)
    3. $L_C = \frac{\Delta_C}{360} 2\pi \quad R_C = \frac{10.9894}{360}(2\pi)(3000)$
       $L_C = 575.4049...'$
       $L_C = 575.40'$ (rounded value)
    4. $T_S = (R_C + p)\tan(\Delta/2) + k$
    5. $E_S = (R_C + p)\left(\frac{1}{\cos \Delta/2} - 1\right) + p$

6. *Route Location and Design*, Hickerson provides two methods for determining p and k transition spiral values. The formula method from Hickerson's *Route Location and Design* pg. 375 is shown below;

$$p = L_s\left[0.00145444\ \theta_s - 1.582315\ \theta_s^{\,3}(10)^{-8} + 1.022426\ \theta_s^{\,5}(10)^{-13}\ldots\right]$$

$$k = L_s\left[0.5 - 5.076957\ \theta_s^{\,2}(10)^{-6} + 4.295915\ \theta_s^{\,4}(10)^{-11}\ldots\right]$$

Calculating using these formulas and the length of spiral and theta calculated above:

p = 0.612′ and k = 104.996′

Hickerson's *Route Location and Design* also provides Functions of Unit Spiral Length Tables for interpolating unit values p_{unit} and k_{unit}. These are calculated by setting L_s equal to 1, and tabulated for integer values of θ_s. Interpolating from the table p_{unit} = 0.002917 and k_{unit} = 0.49998.

The values above are for a unit spiral length and need to be adjusted for L_s. Multiply the unit values by L_s to obtain the actual values for p and k.

$p = p_{unit}$ (L_s) = (0.002917) (210) = 0.612473′ rounding p = 0.612′

$k = k_{unit}$ (L_s) = (0.49998) (210) = 104.995713′ rounding k = 104.996′

Therefore:

T_s = (3000 + 0.612) tan (15/2) + 104.996′

T_s = 500.034'

T_s = 500.03′ (rounded value)

E_s = (3000 + 0.612) (1/cos(15/2) - 1) + 0.612′

E_s = 26.504′

E_s = 26.50′(rounded value)

7. Determine the Stations for TS, SC, CS and ST:

TS Station = PI Station - T_s = [243+18.72] - 500.03′ = 238+18.69

SC Station = TS Station + L_s = [238+18.69] + 210′ = 240+28.69

CS Station = SC Station + L_c = [240+28.69] + 575.40′ = 246+04.09

ST Station = CS Station + L_s = [246+04.09] + 210′ = 248+14.09

Example 3-2: Circular Curve

Given: Δ = 7°00′00″

R = 5,700 feet

e_{max} = 8%

PI Station = 154+56.42

Design Speed = 60 mph

Refer to Appendix H.2.1 for a diagram of the different elements of a circular curve and Appendix H.2.2 for the associated definitions for these different elements.

Problem: According to Chapter 3, Section 3.2.1 use a circular curve when the superelevation is less than 7%. From Chapter 3, Exhibit 3-5, e is 3% for V = 60 mph and R = 5700′, therefore, use a circular curve. Calculate the curve parameters by using the circular curve formulas provided in Appendix H.2.3.

Solution: The following steps apply:

1. Calculate the Tangent Distance:

$$T = R(\tan(\Delta / 2)) = 5700(\tan(7 / 2))$$

$$T = 348.6269'$$

$$T = 348.63' \text{ (rounded value)}$$

2. Calculate the Length of Curve:

$$L = \frac{\Delta}{360} 2\pi R = \frac{7}{360}(2\pi)(5700)$$

$$L = 696.3863'$$

$$L = 696.39' \text{ (rounded value)}$$

3. Calculate the External Distance:

$$E = \frac{R}{\cos(\Delta/2)} - R = \frac{5700}{\cos(7/2)} - 5700$$

$$E = 10.6515'$$

$$E = 10.65' \text{ (rounded value)}$$

4. Length of Long Chord:

$$LC = 2R(\sin(\Delta / 2)) = (2)(5700)(\sin(7 / 2))$$

$$LC = 695.9533'$$

$$LC = 695.95' \text{ (rounded value)}$$

5. Calculate the Middle Ordinate:

$$M = R(1 - \cos(\Delta / 2)) = 5700(1 - \cos(7 / 2))$$

$$M = 10.6316'$$

$$M = 10.63' \text{ (rounded value)}$$

6. Stations are as follows:

PC Station = PI Station - T = [154+56.42] - 348.63′ = 151+07.79

PT Station = PC Station + L = [151+07.79] + 696.39′ = 158+04.18

Example 3-3: Reverse Curve Superelevation Transition - Continuously Rotating Plane between Two Circular Curves

Given: A two-lane, two-way, rural roadway with a design speed of 45 mph and the following reverse curves (circular):

Curve 1	Curve 2
PI Station = 27+27.45	PI Station = 46+47.67
Δ = 73° 08' 53" RT	Δ = 61° 14' 40" LT
R = 1,800 feet	*R* = 1,050 feet
PC Station = 13+91.92	PC Station = 40+26.15
PT Station = 36+89.94	PT Station = 47+92.30

Problem: Calculate the reverse curve superelevation transition, assuming a continuously rotating plane, between the two circular curves.

Solution:

1. Determine if the curves meet the criteria for superelevation transition by the continuous rotating plane method.

From Chapter 3, Exhibit 3-5**:**

Curve 1 requires a 5% superelevation ($e1$), with 110′ of Runoff ($L1$), and 44′ of Tangent Runout ($TR1$) for normal superelevation development.

Curve 2 requires a 7% superelevation ($e2$), with 154′ of Runoff ($L2$), and 44′ of Tangent Runout ($TR2$) for normal superelevation development.

The tangent distance between the two curves is:

PC2 Sta. – PT1 Sta. = [40+26.15] – [36+89.94] = 336.21′

The distance outside of the curves required for normal superelevation development is 70% of the runoff for each curve + the runout distances. For these curves, normal superelevation transitions between the curves would require:

$0.7\times\ (L1 + L2) + TR1 + TR2 = 0.7\times\ (110.00' + 154.00') + 2\times 44' = 272.80'$

The length of normal crown between transitions is 336.21′ – 272.80′ = 63.41′. The *TR* distance for all superelevated curves with a design speed of 45 mph is 44′. The length of normal crown section provided (63.41′) is less than twice the *TR* distance (2 x 44′ = 88′) and therefore, it is not desirable to attain a normal crown section. The continuously rotating plane method is applicable in this situation.

Note that the minimum tangent distance between these two curves would be 70% of the two runoff distances, or 184.80′. Any tangent distance less than this would require either an increase in the normal transition rate or locating more of the transitions on the curves if the curves cannot be moved further away from each other. Either option requires approval of the Highways Engineer as documented in the Alignment and Grade Review Report (AGR Report).

2. Locate the stations of full superelevation.

For continuous rotating plane transitions, the points of full superelevation are held and the transitions are combined into a continuous transition with a constant rate of change.

Points of full super elevation are determined normally, that is 30% of the standard runoff distances onto each curve.

The point where the superelevation starts to transition from 5% RT (point A on the exhibit below) is:

Station A = PT1 station – 0.3($L1$) = [36+89.94] – 0.3 x (110.00′) = Sta. 36+56.94

The point where the transition ends at full 7% superelevation LT (point C on the exhibit below) is:

Station C = PC2 station + 0.3(L2) = [40+26.15] + 0.3 x (154.00′) = Sta. 40+72.35

3. Determine the location of level roadway (point B on the exhibit below).

The total length of continuous superelevation transition (L_{REV}) is the distance between points A and C.

L_{REV} = Station C – Station A = [40+72.35] – [36+56.94] = 415.41′

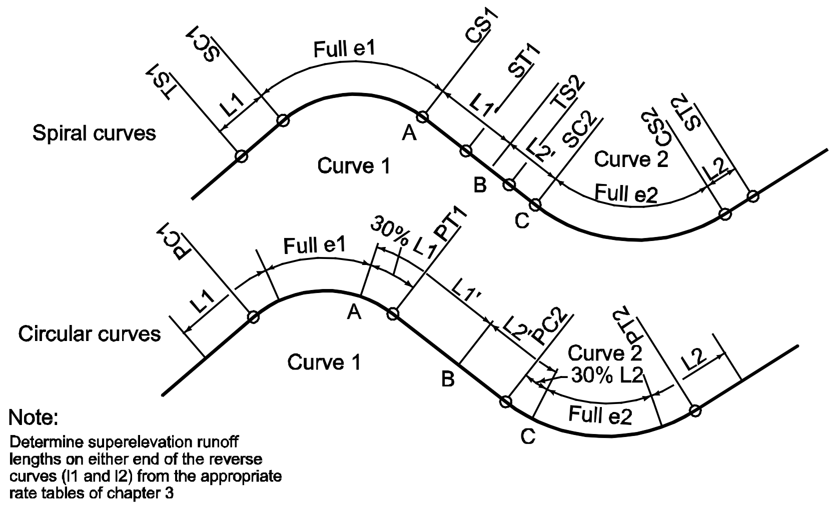
The length of superelevation transition from 5% RT to level ($L1'$) is the distance between points A and B.

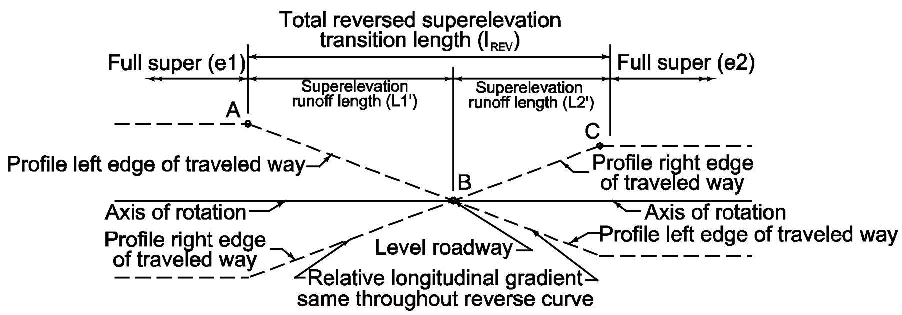
$$L1' = \frac{e1}{(e1+e2)} \times L_{REV} = \frac{5}{(5+7)} \times 415.41' = 173.09'$$

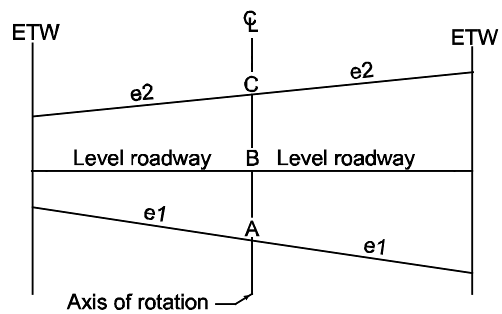
Station B = Station A + $L1'$ = [Station 36+56.94] + 173.09 = 38+30.03

$L2'$ can either be determined by subtracting Station B from Station C, or from the following equation:

$$L2' = \frac{e2}{(e1+e2)} \times L_{REV} = \frac{7}{(5+7)} \times 415.41' = 242.32'$$







For checking the superelevation at a given station (point *X*) within the transition, identify whether the location is within *L1′* or *L2′*. If the station is less than Station B, it falls within L1′; otherwise, it is within *L2′*.

$$e_x = \frac{\text{Station B} - \text{Station X}}{L1'} \times e1 \quad \text{or} \quad \frac{\text{Station X} - \text{Station B}}{L2'} \times e2$$

Determining the superelevation at a point can be useful in checking rollover and the effect of cross slope on approach turning movements, drainage or other cross slope critical criteria, and elevation/clearance for overhead structures.

In this example, if one wanted to determine the superelevation at Station 37+20.00:

37+20.00 is less than 38+30.03, therefore is located within the *L1′* section.

$$e = \frac{[38+30.03]-[37+20.00]}{173.09'} \times 5\% \text{ RT} = 3.18\% \text{ RT (rounded)}$$

Example 3-4: Reverse Curve Superelevation Transition - Continuously Rotating Plane between Two Curves with Spiral Transitions

Given: A four-lane, two-way, open roadway with a design speed of 55 mph and the following reverse curves (w/ spiral transition):

Curve 1	Curve 2
PI Station = 314+76.54	PI Station = 323+93.50
Δ = 23° 30' 00" LT	Δ = 21° 18' 00" RT
R = 1,150 feet	R = 1,500 feet

Problem: Calculate the reverse curve superelevation transition, using a continuously rotating plane between the two curves with spiral transitions.

Solution:

1. Determine if the curves meet the criteria for superelevation transition by the continuous rotating plane method.

   From Chapter 3, Exhibit 3-6**:**

   Curve 1 requires an 8% superelevation ($e1$), with 312′ of Runoff ($L1$) which will coincide with the Spiral Transition ($L1 = Ls1$), and 78′ of Tangent Runout ($TR1$) for normal superelevation development.

   Curve 2 requires a 7% superelevation ($e2$), with 273′ of Runoff ($L2$) which will coincide with the Spiral Transition ($L2 = Ls2$), and 78′ of Tangent Runout ($TR2$) for normal superelevation development.

   Using spiral formulas found in Appendix H.1.3, the following parameters are calculated:

Curve 1	Curve 2
PI Station = 314+76.54	PI Station = 323+93.50
Δ = 23° 30' 00" LT	Δ = 21° 18' 00" RT
R = 1,150'	R = 1,500'
L_s = 312'	L_s = 273'
θ_s = 7° 46' 20"	θ_s = 5° 12' 50"
p = 3.52464'	p = 2.06964'
k = 155.90436'	k = 136.46233'
T_s = 395.84'	T_s = 418.92'
Δ_c = 7° 57' 20"	Δ_c = 10° 52' 20"
L_c = 159.68'	L_c = 284.63'
TS Station = 310+80.70	TS Station = 319+74.58
SC Station = 313+92.70	SC Station = 322+47.58
CS Station = 315+52.38	CS Station = 325+32.21
ST Station = 318+64.38	ST Station = 328+05.21

   The tangent distance between the two curves is:
   TS2 Sta. – ST1 Sta. = [319+74.58] – [318+64.38] = 110.20′

The distance outside of the curves required for normal superelevation development is the sum of the Tangent Runout distances:

$TR1 + TR2 = 78.00' + 78.00' = 156.00'$

The length of normal crown between transitions is 110.20′ – 156.00′ = -45.80′. This distance is less than 2 times the *TR* length (2 x 78′ = 156′), and the continuous rotating plane method is applicable in this situation.

2. Locate the stations of full superelevation.

For continuous rotating plane transitions, the points of full superelevation are held and the transitions are combined into a continuous transition with a constant rate of change.

The points of full superelevation are the SC and CS of each curve, with the entire circular curve section between these points at the full superelevation. The end of full 8% LT (point A on the exhibit below) is the CS of Curve 1, Station 315+52.38 and the SC of Curve 2, Station 322+47.58 is the beginning of full 7% super RT (point C on the exhibit below).

3. Determine the location of level roadway (point B on the exhibit below).

The total length of continuous superelevation transition (L_{REV}) is the distance between points A and C.

L_{REV} = Station C – Station A = [322+47.58] – [315+52.38] = 695.20′

The length of superelevation transition from 8% LT to level ($L1'$) is the distance between points A and B.

$$L1' = \frac{e1}{(e1+e2)} \times L_{REV} = \frac{8}{(8+7)} \times 695.20' = 370.77'$$

Station B = Station A + $L1'$ = [315+52.38] + 370.77′ = 319+23.15

This point is not identified in the plans specifically, except in the cross sections, but it indicates where the roadway surface drainage changes, and is helpful in determining the cross slope at any point within the transition. From 319+23.15 the roadway drains left to right back on station, and drains right to left ahead on station.

$L2'$ can be calculated similarly:

$$L2' = \frac{e2}{(e1+e2)} \times L_{REV} = \frac{7}{(8+7)} \times 695.20' = 324.43'$$

For checking the superelevation at a given station (point X) within the transition, identify whether the location is within $L1'$ or $L2'$. If the station is less than Station B, it falls within $L1'$; otherwise, it is within $L2'$.

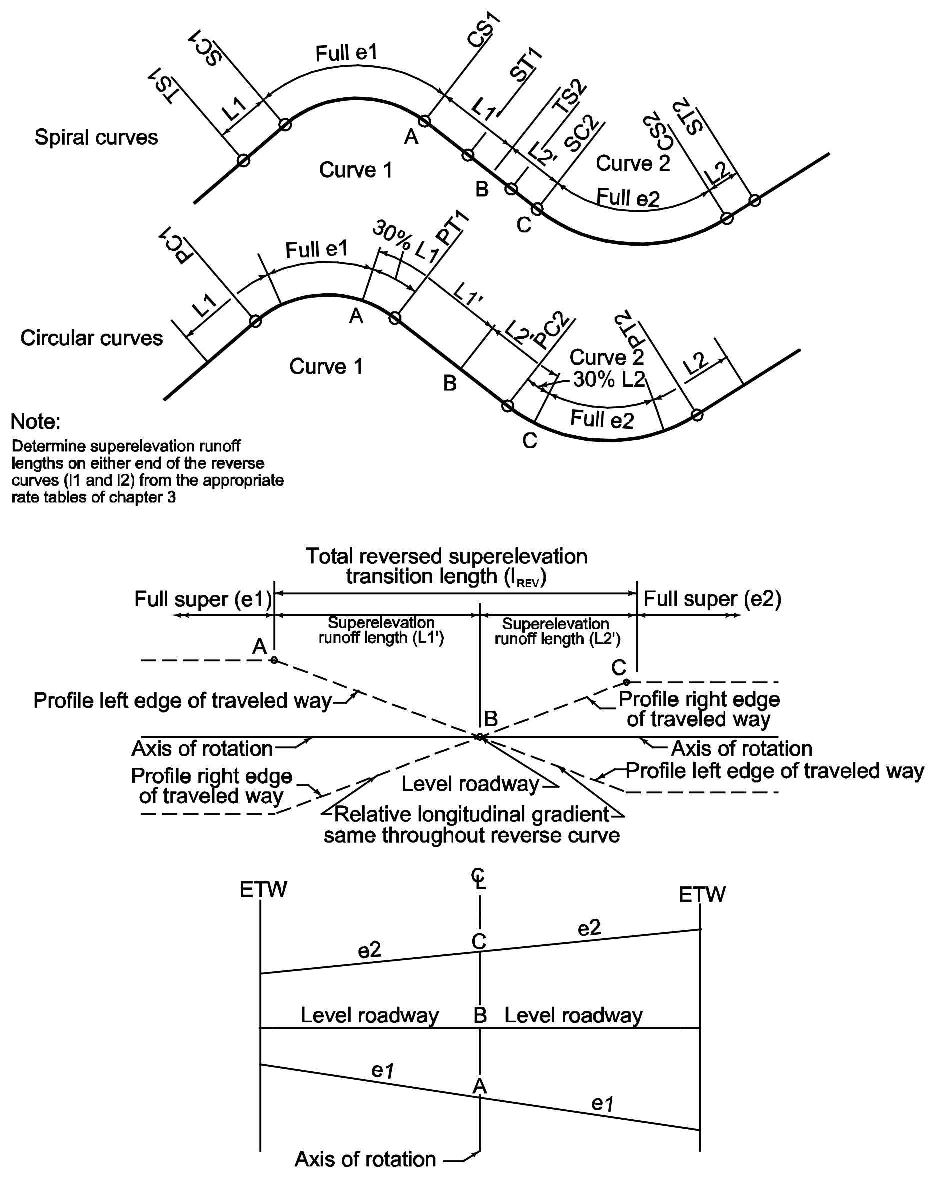
$$e_x = \frac{\text{Station B} - \text{Station X}}{L1'} \times e1 \quad \text{or} \quad \frac{\text{Station X} - \text{Station B}}{L2'} \times e2$$

Determining the superelevation at a point can be useful in checking rollover and the effect of cross slope on approach turning movements, drainage or other cross slope critical criteria, and elevation/clearance for overhead structures.

In this example, if one wanted to determine the superelevation at Station 321+00.00:

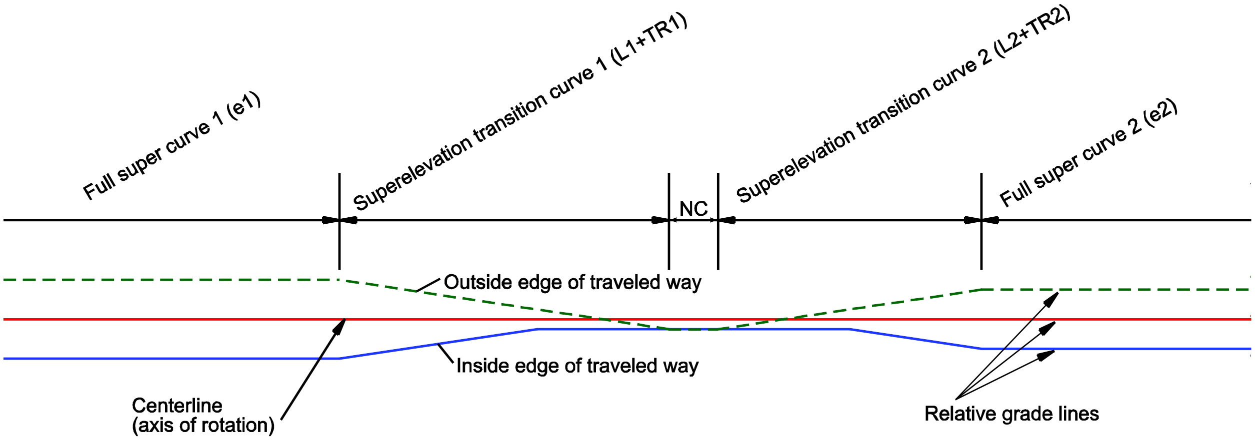
321+00.00 is greater than 319+23.15, therefore is located within the *L2′* section.

$$e = \frac{[321+00.00]-[319+23.15]}{324.43'} \times 7\% \text{ RT} = 3.82\% \text{ RT (rounded)}$$



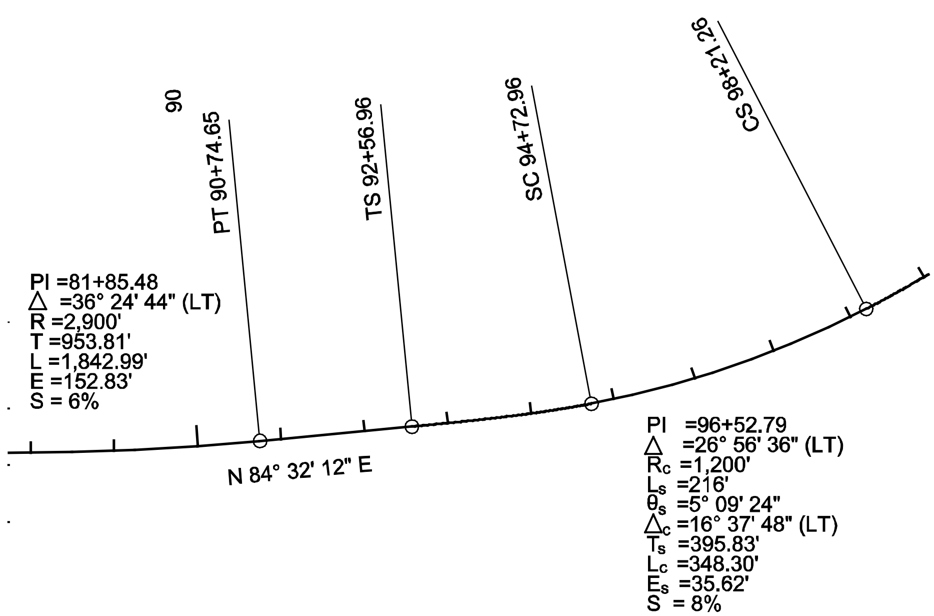
Example 3-5: Broken Back Curve Application

Given: Superelevation transition for horizontal curves in the same direction (broken-back curves). The exhibit below represents the relative grade lines of each edge of the traveled way for a roadway transitioning through two superelevated curves in the same direction:



When the standard transition lengths result in a normal crown (NC) section between the curves less than 200 feet long, do not transition down to normal crown. Instead, transition down to a section with less superelevation, but not less than the normal crown cross slope that can be maintained for at least 200 feet.

Problem: Given the following alignment, determine the superelevation transition between the curves assuming a 60 mph design speed, two-lane, two-way roadway rotated about the centerline, and a normal crown of 2 percent:



Solution:

1. Determine the normal transition lengths and locations for each curve.

   For a design speed of 60 mph, Exhibit 3-5 indicates that 27 feet of transition length is needed for each 1 percent change in cross slope.

   The first curve is circular, with 6 percent superelevation. For circular curves, 30 percent of the runoff length is located on the curve:

   Start of transition (6%) = [PT station] – 0.3(*L*) = [90+74.65] – 0.3(162′) = Sta. 90+26.05

   End of transition (NC) = [90+26.05] + *L* + *TR* = [90+26.05] + 162′ + 54′ = Sta. 92+42.05

   For the second curve, the 8 percent runoff length is applied through the corresponding spiral transition length (216 feet). The tangent runout distance (54 feet) back from the TS station is the station where normal crown would end, and the transition to 8 percent superelevation begins:

   Start of transition (NC) = [TS station] – *TR* = [92+56.96] – 54′ = Sta. 92+02.96

   End of transition (8%) = [SC station] = Sta. 94+72.96

2. Check the length of normal crown between transitions:

   Length of NC provided = [92+02.96] - [92+42.05] = –39.09′

   If the length of NC section provided is 200 feet or more, standard transitions may be provided. Otherwise, proceed on to Step 3. (A negative value, as in this case, indicates the distance that the transition locations overlap each other.)

3. Determine the intermediate rate of superelevation that can be held for at least 200 feet between transitions using the following equation:

$$S' = \frac{200' - \text{length of NC provided (feet)}}{2 \times \text{length for 1\% change (feet)}} - NC$$

where:

S′ = intermediate percent superelevation

NC = normal crown cross slope

$$S' = \frac{200' - (-39.09')}{2 \times 27'} - 2 = \frac{239.09'}{54'} - 2 = 2.43\text{, round} \Rightarrow 3\%$$

Note: Round up to the next integer value equal to or greater than the normal crown cross slope (2% is typical for paved roadways).

4. Determine the stations within the transitions where the superelevation is 3 percent:

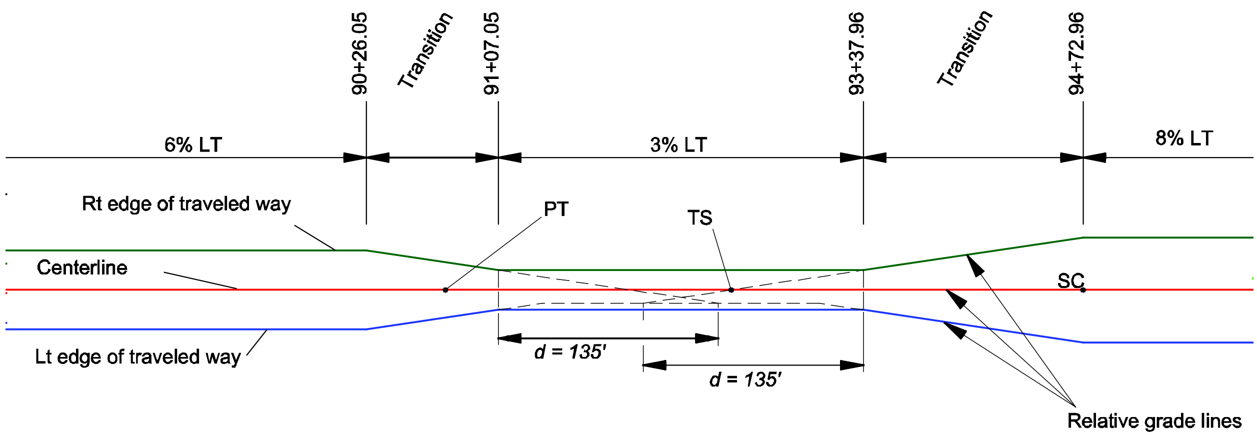
Working from the end of each transition where NC would be provided, the distance, d, to the 3 percent superelevated section is calculated:

$$d = (S' + \text{NC}) \text{ x length for 1\% change (feet)} = (3 + 2) \text{ x } 27' = 135'$$

Station of start of constant 3% = [92+42.05] - 135′ = Sta. 91+07.05

Station of end of constant 3% = [92+02.96] + 135′ = Sta. 93+37.96

The figure below represents the relative grade lines for the edge of traveled way for this example.



These transitions would be indicated in the plans by the stationing callouts on the superelevated typical section, rather than transitioning back and forth between typicals.

For example:

XX+XX.XX to 90+26.05	6% LT
90+26.05 to 91+07.05	Trans. 6% LT to 3% LT
91+07.05 to 93+37.96	3% LT
93+37.96 to 94+72.96	Trans. 3% LT to 8% LT
94+72.96 to YY+YY.YY	8% LT

Example 3-6: Compound Curve Application

Given: $\Delta = 40°$
$R1 = 600$ feet
$R2 = 250$ feet
$p = 5'$
Refer to Appendix H.3.1 for a diagram of the different elements of a compound curve.

Problem: Determine the curve data for the compound curve.

Solution: Use the compound curve formulas from Appendix H.3.2 to calculate the curve parameters:

1. $T_1 = (R_2 + p)\tan(\Delta/2) = (250'+5')\tan(40°/2)$

   $T_1 = 92.81'$

2. $\Delta_1 = \cos^{-1}\left[\dfrac{R_1 - R_2 - p}{R_1 - R_2}\right] = \cos^{-1}\left[\dfrac{600'-250'-5'}{600'-250'}\right]$

   $\Delta_1 = 9.6963°$

   $\Delta_1 = 9°41'47''$ (rounded value)

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1 = 92.81'+(600'-250')\sin(9.6963°)$

   $T = 151.7591'$

   $T = 151.76'$ (rounded value)

4. $T_2 = T_1 - R_2 \sin\Delta_1 = 92.81'-(250')\sin(9.6963°)$

   $T_2 = 50.7036'$

   $T_2 = 50.70'$ (rounded value)

5. $E = \dfrac{R_2 + p}{\cos(\Delta/2)} - R_2 = \dfrac{250'+5'}{\cos(40°/2)} - 250'$

   $E = 21.3653'$

   $E = 21.37'$ (rounded value)

6. $M = R_2 - (R_2 \cos(\Delta / 2 - \Delta_1)) = 250' - \left(250' \cos\left(\frac{40°}{2} - 9.6963°\right)\right)$

$M = 4.0316'$

$M = 4.03'$ (rounded value)

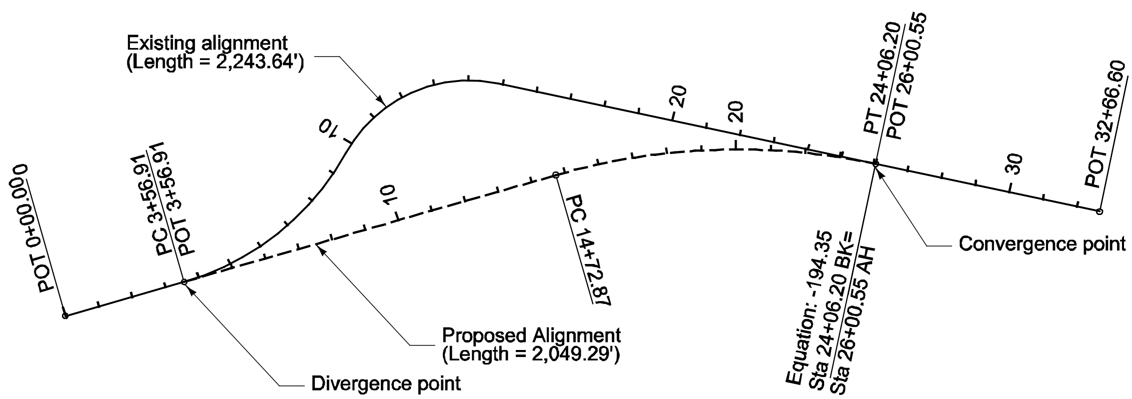
7. $y = (R_2 + p) - R_2 \cos \Delta_1 = (250' + 5') - (250') \cos(9.6963°)$

$y = 8.5714'$

$y = 8.57'$ (rounded value)

Example 3-7: Station Equation Applications – Negative (Gap) Equation

Given: An existing compound curve is reconstructed with a proposed simplified alignment:



Problem: The proposed alignment reduces the overall length of the alignment, creating a stationing discrepancy at the end of the project. Determine a station equation to correct the stationing discrepancy.

Solution: Determine the negative (gap) station equation as follows:

1. Determine Back (BK) Station

   BK Sta. = Divergence Sta. + Proposed Alignment Length
   BK Sta. = [3+56.91] + 2,049.29′
   BK Sta. = 24+06.20

2. Determine Ahead (AH) Station

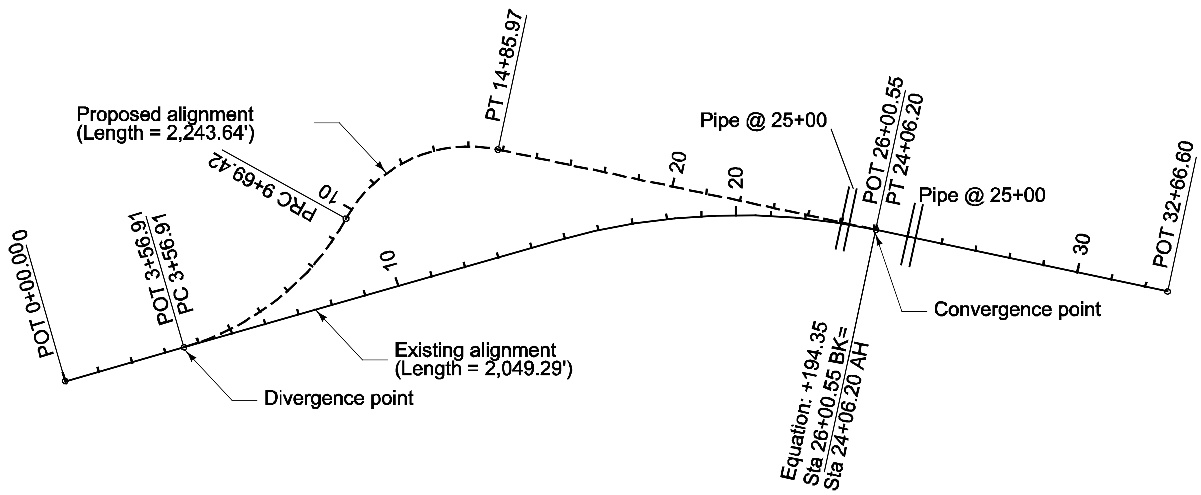
   AH Sta. = Divergence Sta. + Existing Alignment Length
   AH Sta. = [3+56.91] + 2,243.64′
   AH Sta. = 26+00.55

3. Determine Station Equation

   Sta. Equation = BK Sta. – AH Sta.
   Sta. Equation = [24+06.20] – [26+00.55]
   Sta. Equation = -194.35′

Example 3-8: Station Equation Applications – Positive (Overlap) Equation

Given: An existing alignment is reconstructed with a proposed reverse curve:



Problem: The proposed alignment increases the overall length of the alignment, creating a stationing discrepancy at the end of the project. Determine a station equation to correct the stationing discrepancy.

Solution: Determine the positive (overlap) station equation as follows:

1. Determine Back (BK) Station

   BK Sta. = Divergence Sta. + Proposed Alignment Length
   BK Sta. = [3+56.91] + 2,243.64′
   BK Sta. = 26+00.55

2. Determine Ahead (AH) Station

   AH Sta. = Divergence Sta. + Existing Alignment Length
   AH Sta. = [3+56.91] + 2,049.29′
   AH Sta. = 24+06.20

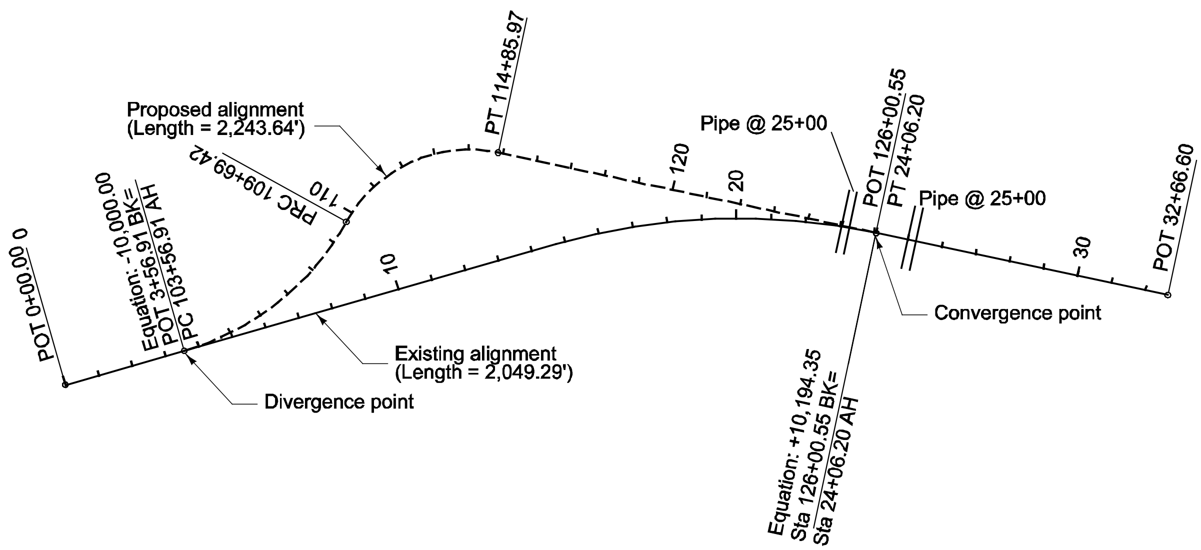
3. Determine Station Equation

   Sta. Equation = BK Sta. – AH Sta.
   Sta. Equation = [26+00.55] – [24+06.20]
   Sta. Equation = +194.35′

Note: This scenario can create an undesirable condition where project features can have coincident stations (see culverts in figure above for example). See the following example for a solution to this condition.

Example 3-9: Station Equation Applications – Alternate Stationing

Given: An existing alignment is reconstructed with a proposed reverse curve:



Problem: The proposed alignment increases the overall length of the alignment, creating a stationing discrepancy at the end of the project. Determine alternate stationing for the proposed alignment to correct the stationing discrepancy and to avoid coincident stations.

Solution: Determine the alternate stationing and station equation as follows:

1. Establish Alternate Alignment Ahead (AH) Stationing at Divergence

   AH Sta. = Divergence BK Sta. – Sta. Equation
   AH Sta. = [3+56.91] – (-10,000.00')
   AH Sta. = 103+56.91

2. Determine Back (BK) Station at Convergence

   BK Sta. = Divergence AH Sta. + Proposed Alignment Length
   BK Sta. = [103+56.91] + 2,243.64'
   BK Sta. = 126+00.55

3. Determine Ahead (AH) Station at Convergence

   AH Sta. = Divergence BK Sta. + Existing Alignment Length
   AH Sta. = [3+56.91] + 2,049.29'
   AH Sta. = 24+06.20

4. Determine Station Equation at Convergence

    Sta. Equation = Convergence BK Sta. – Convergence AH Station
    Sta. Equation = [126+00.55] – [24+06.20]
    Sta. Equation = +10,194.35′

Note: This scenario corrects the undesirable condition where project features can have coincident stations (see culverts in figure above for example). See the previous example describing the undesirable condition.

Vertical Alignment Example Calculations

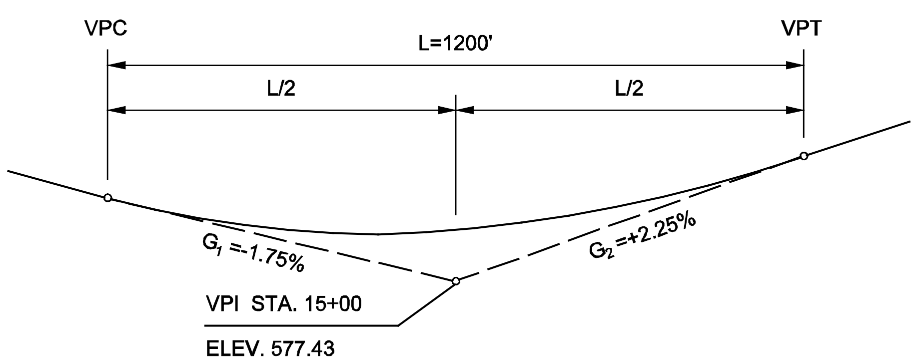
Example 4-1: Compute Elevations and Stations at Specific Points on a Symmetrical Sag Vertical Curve

Given: G_1 = -1.75%
G_2 = +2.25%
Elevation of VPI = 577.43′
Station of VPI = 15+00
L = 1,200′
Symmetrical Vertical Curve
Refer to Appendix H.4.1 for a diagram of the different elements of a symmetrical vertical curve and Appendix H.4.2 for the associated definitions for these different elements.

Problem: Compute the vertical curve elevations for each 50-foot station. Compute the low point elevation and stationing.

Solution: The following steps apply:

1. Draw a diagram of the vertical curve and determine the station at the beginning (VPC) and the end (VPT) of the curve.



VPC Station = VPI Sta. – ½ L = [15+00] – (0.5)(1200′) = 9+00
VPT Station = VPI Sta. + ½ L = [15+00] + (0.5)(1200′) = 21+00

2. Use the symmetrical vertical curve formulas from Appendix H.4.3 to calculate the elements of the vertical curve:

$$CURVE\,ELEV. = TAN.ELEV. + Z$$

Where:

Left of VPI (X_1 measured from VPC):	Right of VPI (X_2 measured from VPT):
(a) $TAN\ \ ELEV. = VPC\,ELEV. + G_1\left(\frac{X_1}{100}\right)$	(a) $TAN\ \ ELEV. = VPT\,ELEV. - G_2\left(\frac{X_2}{100}\right)$
(b) $Z_1 = X_1^2\,\frac{(G_2 - G_1)}{200\,L}$	(b) $Z_2 = X_2^2\,\frac{(G_2 - G_1)}{200\,L}$

3. Set up a table to show the vertical curve elevations at the 50-foot stations, substituting the values into the above equations.

Station	Inf.	Tangent Elevation	*X*	X^2	$Z=X^2/60{,}000$[1]	Grade Elevation
9+00	VPC	587.930	0	0	0	587.93
9+50		587.055	50	2,500	0.0417	587.10
10+00		586.180	100	10,000	0.1667	586.35
10+50		585.305	150	22,500	0.3750	585.68
11+00		584.430	200	40,000	0.6667	585.10
11+50		583.555	250	62,500	1.0417	584.60
12+00		582.680	300	90,000	1.5000	584.18
12+50		581.805	350	122,500	2.0417	583.85
13+00		580.930	400	160,000	2.6667	583.60
13+50		580.055	450	202,500	3.3750	583.43
14+00		579.180	500	250,000	4.1667	583.35
14+50		578.305	550	302,500	5.0417	583.35
15+00		577.430	600	360,000	6.0000	583.43
15+50		578.555	550	302,500	5.0417	583.60
16+00		579.680	500	250,000	4.1667	583.85
16+50		580.805	450	202,500	3.3750	584.18
17+00		581.930	400	160,000	2.6667	584.60
17+50		583.055	350	122,500	2.0417	585.10
18+00		584.180	300	90,000	1.5000	585.68
18+50		585.305	250	62,500	1.0417	586.35
19+00		586.430	200	40,000	0.6667	587.10
19+50		587.555	150	22,500	0.3750	587.93
20+00		588.680	100	10,000	0.1667	588.85
20+50		589.805	50	2,500	0.0417	589.85
21+00	VPT	590.930	0	0	0	590.93

[1] The 60,000 value is calculated according to $200L/(G_2\text{-}G_1)$ → (200*1,200)/(2.25 – (-1.75)) = 60,000.

4. Calculate the low point on the curve:

To determine distance "X_T" from VPC: $X_T = \dfrac{LG_1}{G_1 - G_2}$

$$X_T = \frac{LG_1}{G_1 - G_2} = \frac{1200'(-1.75)}{-1.75 - 2.25} = \frac{-2{,}100.00'}{-4.00} = 525.00' \text{ from } VPC$$

To determine low point stationing: $VPC\,Sta. + X_T$

Therefore, the Station at the low point is:

$$VPC_{STA} + X_T = [9 + 00] + (525') = 14 + 25$$

To determine the low point elevation on the vertical curve:

$$ELEV_{LOW\ POINT} = ELEV\ \ VPC - \frac{LG_1^2}{(G_2 - G_1)200}$$

Elevation of the low point on the curve equals:

$$Elev.VPC - \frac{LG_1^2}{(G_2 - G_1)200} = 587.93' - \frac{1{,}200'(-1.75)^2}{(2.25 - (-1.75))200} = 583.34'$$

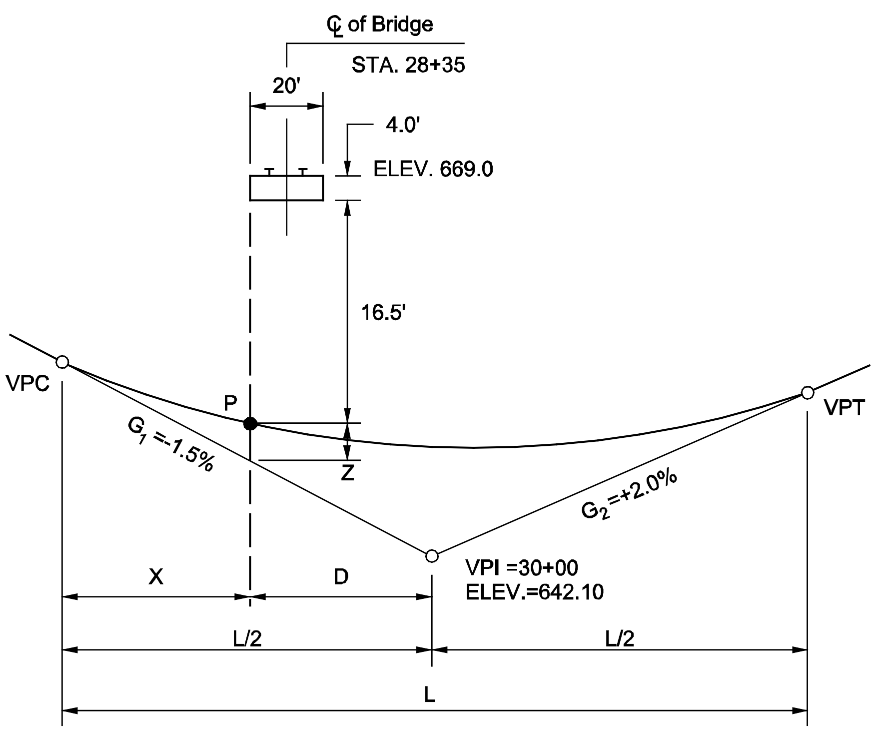
Example 4-2: Symmetrical Vertical Curve Through a Fixed Point

Given: Design Speed = 55 mph
G_1 = -1.5%
G_2 = +2.0%
VPI Station = 30+00
VPI Elevation = 642.10′
Refer to Appendix H.4.1 for a diagram of the different elements of a symmetrical vertical curve and Appendix H.4.2 for the associated definitions for these different elements.

Problem: At Station 28+35, the new highway must pass under the center of an existing railroad which is at elevation 669.00′ at the highway centerline. The railroad bridge that will be constructed over the highway will be 4.0′ in depth, 20.0′ in width and at right angles to the highway. What would be the length of the symmetrical vertical curve that would provide a 16.5′ clearance under the railroad bridge?

Solution:

1. Sketch the problem with known information labeled.



2. Determine the station where the minimum 16.5′ vertical clearance will occur (Point P):

   From inspection of the sketch, the critical location appears to be on the left side of the railroad bridge. The critical station is:

   $$STA.\ P = BRIDGE\,CENTERLINE\,STATION - \frac{1}{2}(BRIDGE\,WIDTH)$$

   $$STA.\ P = [28+35] - \frac{20'}{2}$$

   $$STA.\ P = 28+25$$

3. Determine the elevation of Point P:

   ELEV. P = ELEV. TOP RAILROAD BRIDGE – BRIDGE DEPTH - CLEARANCE

   $$ELEV.P = 669.00' - 4.00' - 16.50'$$

   $$ELEV.P = 648.50'$$

4. Determine distance, *D*, from Point P to VPI:

   $$\begin{aligned} D &= STA.\ VPI - STA.\ P \\ &= [30+00] - [28+25] \\ &= 175' \end{aligned}$$

5. Determine the tangent elevation at Point P:

   $$\begin{aligned} TAN.\ ELEV.\ AT\ \ P &= ELEV.VPI - G_1\left(\frac{D}{100}\right) \\ &= 642.10 - (-1.5)\left(\frac{175}{100}\right) \\ &= 644.73' \end{aligned}$$

6. Determine the vertical curve correction (*Z*) at Point P:

   $$\begin{aligned} Z &= ELEV.\ P - TAN.\ ELEV. \\ &= 648.50' - 644.73' \\ &= 3.77' \end{aligned}$$

7. Solve for *X* using the following equation:

   $$X = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where:

X = Horizontal Distance: Measured from the VPC (or VPT) to any point on the vertical curve (feet)

$a = A$ = Algebraic Difference in Grade: The difference between the two tangent grades (G_1-G_2) (percent)

$b = Z$ = Tangent Offset: The vertical distance from the tangent line to any point on the vertical curve (feet)

$c = D \times Z$ = Product of D (distance from the VPI to the subject point, P) and Z (tangent offset) (square feet)

$$X = \frac{400Z \pm \sqrt{160{,}000Z^2 + 1{,}600ADZ}}{2A}$$

$$X = \frac{400(3.77) \pm \sqrt{160{,}000(3.77)^2 + 1{,}600(3.5)(175)(3.77)}}{2(3.5)}$$

$$X = 564.44' \quad AND \quad X = -133.58' \ (Disregard)$$

8. Using either of the following equations, solve for L:

$$X + D = L/2 \quad or \quad L = 2(X + D)$$

$$L = 2(X + D)$$
$$L = 2(564.44' + 175')$$
$$L = 1{,}478.88'$$

9. Check the critical point assumption from Step 2. Since the sketch is based on an assumed length of curve, the low point of the curve is also at an assumed location. In this example, the tangent grades of the curve are not “sketched” correctly. They indicate that the low point of the curve is on the right side of the VPI. In fact, the low point is on the left side of the VPI, as the magnitude of G_1 is less than that of G_2.

Using the equation for finding the low point of the curve (see example 4-1): $X_T = \frac{LG_1}{G_1 - G_2}$

$$X_T = \frac{LG_1}{G_1 - G_2} = \frac{1478.88'(-1.50)}{-1.50 - 2.00} = \frac{-2{,}218.32'}{-3.50} = 633.81' \text{ from } VPC$$

The station of the low point of the sag is 28+94.37, which is on the right side of the center of the railroad bridge station of 28+35.00. Therefore, the critical point assumption made in Step 2 is confirmed. Proceed to the next step.

Note: If the low point station had been on the left side of the bridge centerline, the length of curve required for clearance would need to be recalculated for the correct critical location on the right side of the bridge. Completing the sketch as accurately as possible for the known elements will lessen the likelihood of assuming the incorrect critical point, particularly for cases where the overhead structure is much wider.

10. Determine if the solution meets the desirable stopping sight distance for the 55 mph design speed. From Exhibit 4-5, the desirable K-value:

    $K = 115$

    The algebraic difference in grades:

    $A = G_2 - G_1 = (+2.0) - (-1.5) = 3.5$

    From Equation 4.4-9, the minimum length of vertical curve which meets the desirable stopping sight distance:

    $$\begin{aligned} L_{MIN} &= KA \\ &= (115) \times 3.5 \\ &= 402.5' \end{aligned}$$

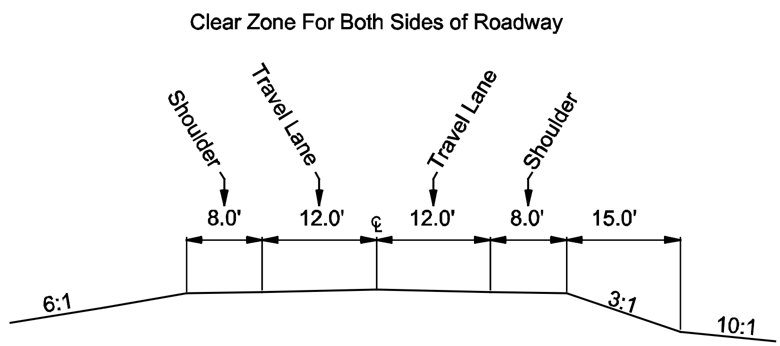
    Therefore, L = 1,478.88′ will provide the desirable stopping sight distance.

    Note: This would be rounded down to 1,450′ for recording on the plans.

Roadside Safety Example Calculations

Example 9-1: Clear Zone for Both Sides of the Roadway

Given: Design Speed = 55 mph
Annual Average Daily Traffic (AADT) = 4,750
Lane Width: 12 feet
Shoulder Width: 8 feet



Problem: Determine the clear zone distance for both sides of the roadway.

Solution: Using the procedure in Chapter 9, Section 9.2.2.2 for each side of the roadway:

1. For the left side of the roadway, the entire slope is flatter than 4:1, so the clear zone can be determined directly from Exhibit 9-1.

   Left Clear Zone Width = 20 feet (Exhibit 9-1)

2. For the right side of the roadway, the 3:1 slope is non-recoverable. The procedure in Chapter 9, Section 9.2.2.2, Step 2 must be used.

3. Checking the recovery area beyond the toe, the slope of 10:1 is flatter than 4:1. This 10:1 slope is then used to determine the clear zone distance required from Exhibit 9-1.

   Right Clear Zone Width = 20 feet (Exhibit 9-1)

4. The recovery area beyond the toe is calculated by subtracting the 8 feet of recoverable slope between the edge of traveled way and the hinge point from the 20 feet obtained in Step 3:

   20′ – 8′ = 12′ Distance beyond the toe

5. Since 12′ > 10′, 12′ will be used as the recovery distance beyond the toe. (Chapter 9, Section 9.2.2.2, Step 2c)

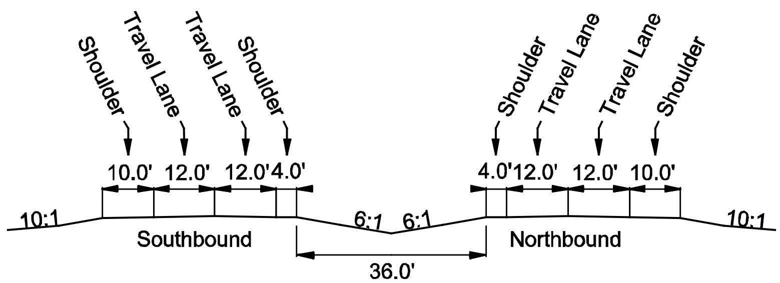
6. Using the 12 feet recovery distance beyond the toe, the total clear zone width is calculated by summing the distance beyond the toe and the distance from the edge of traveled way to the toe:

   8′ + 15′ + 12′ = 35′ Total Right Clear Zone Width

Example 9-2: Clear Zone for a Divided Highway

Given: Design Speed: 70 mph
AADT: 18,000
Lane Width: 12 feet
Outside Shoulder Width: 10 feet
Inside Shoulder Width: 4 feet
Median Width: 36 feet

Clear Zone For a Divided Highway



(Not to Scale)

Problem: Determine the clear zone distances.

Solution: Using the procedure in Chapter 9, Section 9.2.2.2 for each side of each roadway:

1. For the outside in each direction of travel, the slope is flatter than 4:1, so the clear zone can be determined directly from Exhibit 9-1:

   Outside Clear Zone Width = 32 feet (Exhibit 9-1)

2. In the median, for the inside in each direction of travel, the inslope of 6:1 is flatter than 4:1, so a clear zone distance can be obtained from Exhibit 9-1:

   Median Clear Zone Width = 32 feet (Exhibit 9-1)

3. The toe of the backslope is located at the center of the median which is 22 feet (4’ + 18’) from each inside edge of traveled way.

   22’ < 32’, so the toe is within the clear zone.

4. Since the toe is within the clear zone, the median toe must be checked for traversability. Using Exhibit 9-10, the median is determined to be traversable.

5. The percentage of the clear zone available up to the toe of the backslope is computed:
   22′ ÷ 32′ = 0.6875

6. This value is subtracted from Step 2 and multiplied by the adjusted backslope clear zone factor of 30 feet obtained from Exhibit 9-6:
   (1 - 0.6875) x 30′ = 9.38′ (Clear zone distance required beyond the toe)

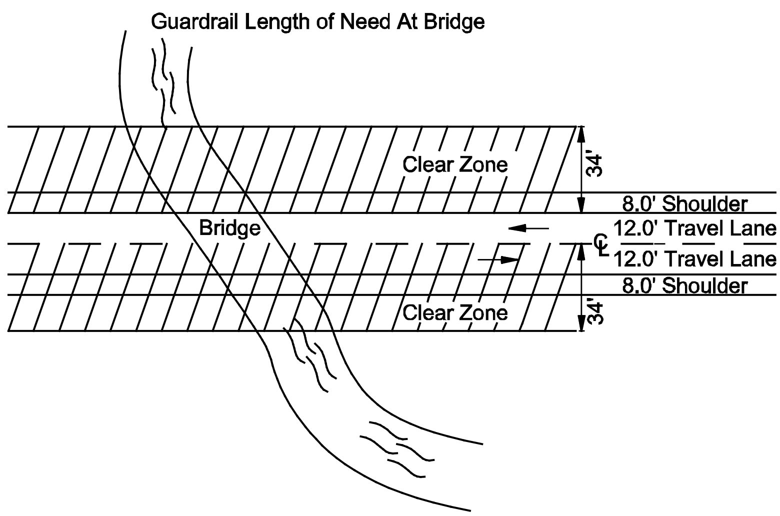
7. The total clear zone is obtained by adding the value from Step 6 and the distance to the toe:

   9.38′ + 22′ = 31.38′

8. This value is rounded up to the next foot, yielding a Total Median Clear Zone Width of 32 feet.

Example 9-3: Guardrail Length of Need for Obstacle Extending Beyond the Clear Zone

Given: Design Speed: 55 mph
AADT: 4,750
Shoulder Width: 8 feet
Lane Width: 12 feet
Clear Zone Width: 34 feet
Non-flared Guardrail (flared guardrail not allowed) with face of rail at edge of shoulder



Problem: Determine the length of need for guardrail on each side of the road on this end of the bridge (obstacle extends to the edge of the clear zone).

Solution:

1. Using Exhibit 9-16 the runout length is obtained by linear interpolation between 50 and 60 mph:

   (160′ + 210′) ÷ 2 = 185′

2. A non-flared design will be used, Equation 9.4-2 is applied.

   $$X = \frac{L_R(L_O - L_1)}{L_O}$$

   a. For a departure to the right:

      L_R = 185 feet
      L_O = L_C = 34 feet
      L_1 = 8 feet

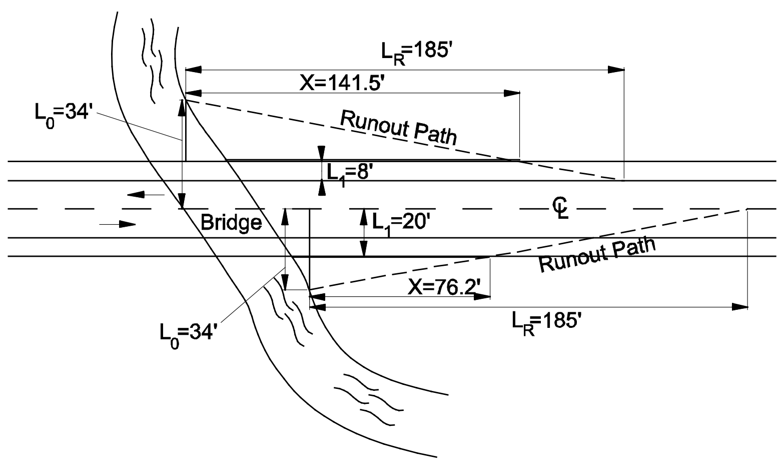
      X = [185′ x (34′ - 8′)] ÷ 34′ = 141.5′ Length of Need

b. For a departure to the left:

L_R = 185 feet
L_O = L_C = 34 feet
L_1 = 12′ + 8′ = 20 feet

X = [185′ x (34′ - 20′)] ÷ 34′ = 76.2′ Length of Need

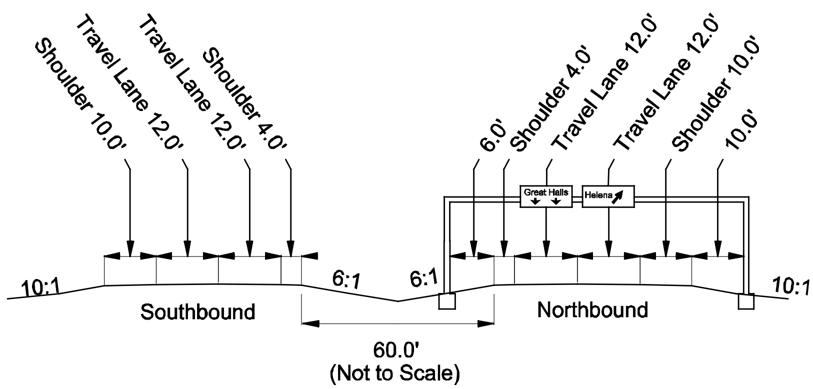
NOTE: Some of the length of need will be covered by terminal end sections and the bridge approach section. These lengths should be determined before computing the final length of rail required for each side.

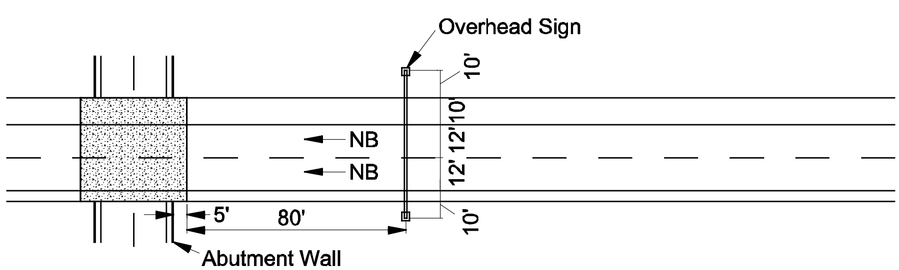


Example 9-4: Controlling Length of Need for Multiple Obstacles

Given: Design Speed: 70 mph
AADT: 18,000
Outside Shoulder Width: 10 feet
Inside Shoulder Width: 4 feet
Lane Width: 12 feet
Clear Zone Width: 32 feet
Non-Flared Guardrail

Guardrail Length of Need for Bridge and Overhead Sign





Problem: Determine if the bridge or the sign controls the barrier length and find the length of need for guardrail on each side of the NB side of the highway.

Solution:

1. Using Exhibit 9-16 the runout length is determined to be 360 feet.

2. A non-flared design will be used. Equation 9.4-2 will be used to compute length of need.

3. For a left side departure:

   a. The length of need for the sign support is computed as follows:
   L_R = 360 feet
   L_O = 4′ + 6′ = 10 feet (hazard is within the clear zone)
   L_1 = 4 feet

   X = [360′ x (10′ - 4′)] ÷ 10′ = 216.0′ Length of Need

   b. The length of need for the bridge abutment wall is computed as follows:

   L_R = 360 feet
   L_O = L_C = 32 feet (hazard extends beyond the clear zone)
   L_1 = 4 feet

   X = [360′ x (32′ - 4′)] ÷ 32′ = 315.0′ Length of Need

   c. Guardrail must extend at least 315 feet from the abutment wall and 216 feet from the sign support. Adding 216 feet to the 85 feet from the abutment wall to the sign support gives 301 feet, which is less than 315 feet, so the bridge drop-off is the controlling feature and the final length of need is 315 feet from the abutment wall.

4. For a right side departure:

   a. The length of need for the sign support is computed as follows:

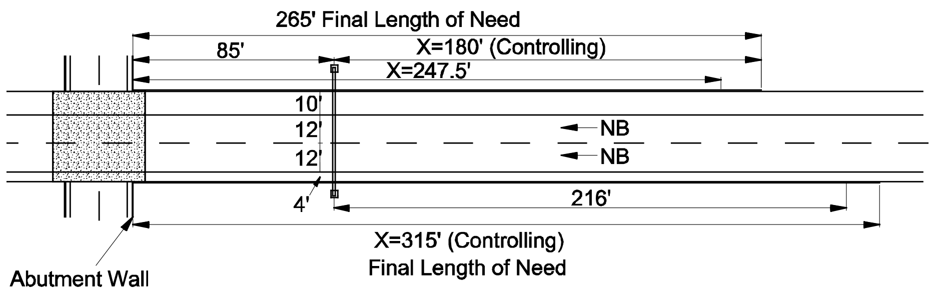
   L_R = 360 feet
   L_O = 10′ + 10′ = 20 feet
   L_1 = 10 feet

   X = [360′ x (20′ - 10′)] ÷ 20′ = 180.0′ Length of Need

   b. The length of need for the bridge abutment wall is computed as follows:
   L_R = 360 feet
   L_O = L_C = 32 feet (hazard extends beyond the clear zone)
   L_1 = 10 feet

   X = [360′ x (32′ - 10′)] ÷ 32′ = 247.5′ Length of Need

c. Guardrail must extend at least 247.5 feet from the abutment wall and 180 feet from the sign support. Adding 180 feet to the 85 feet from the abutment wall to the sign support gives 265 feet, which is greater than 247.5 feet, so the sign is the controlling feature and the final length of need is 265 feet from the abutment wall.



Example 9-5: Minimum Length of Culvert

Background: The length of large culverts with concrete edge protection must be long enough so that the top portion of concrete edge protection is out of the clear zone. This is typically straightforward on culverts that are perpendicular to the roadway. However, when drawing culverts on a skew, make sure that the skewed corners of the concrete edge protection are out of the clear zone.

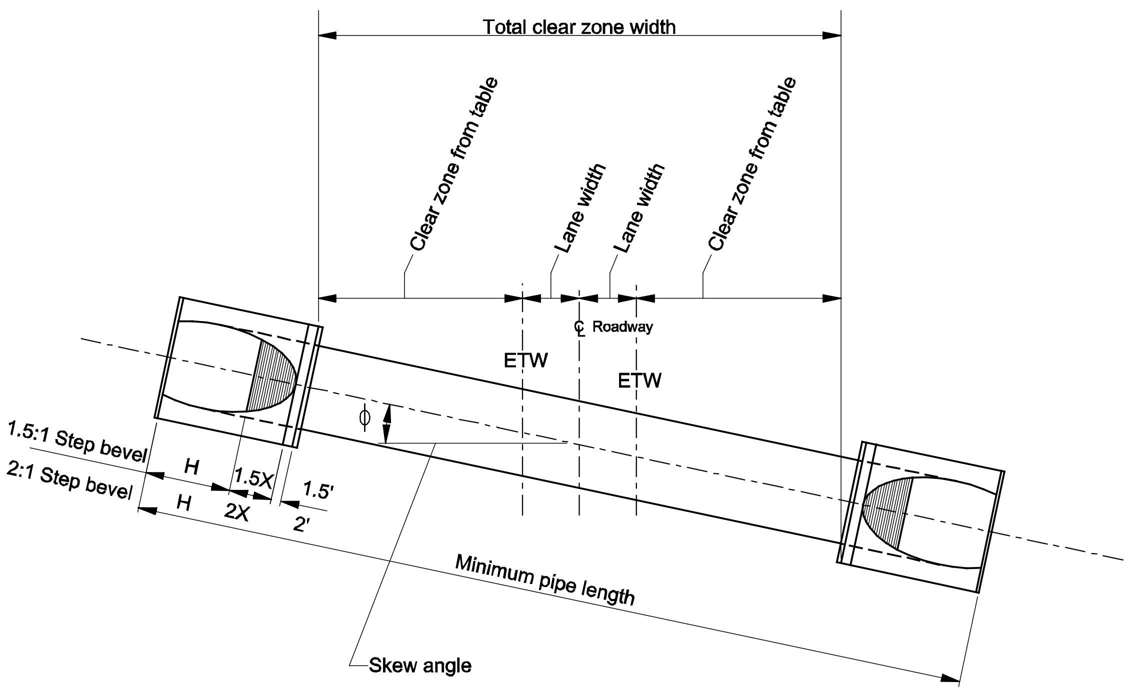
Use the following formulas to calculate the minimum lengths of skewed culverts to ensure that the concrete edge protection is out of the clear zone:

1.5:1 Step Bevel Formula:

$$\frac{(\sin\phi\,(0.5D + 4') \times 2 + \text{Total Clear Zone Width})}{\cos\phi} + (1.5' + 1.5X + H) \times 2 = \text{min. pipe length}$$

2:1 Step Bevel Formula:

$$\frac{(\sin\phi\,(0.5D + 4') \times 2 + \text{Total Clear Zone Width})}{\cos\phi} + (2' + 2X + H) \times 2 = \text{min. pipe length}$$



Given: 18' Diameter Circular Metal Pipe

ϕ = 12 degree skew

2:1 Step Bevel Ends with Concrete Edge Protection on Inlet and Outlet

Clear Zone Distance from ETW = 36'

2 lane roadway with 12' lanes

Culvert Dimensions from Detailed Drawings:

D = 18'

X = 4.5'

H = 18'

Problem: Determine the minimum overall length of culvert to make sure that the concrete edge protection is out of the clear zone.

Solution:

2:1 Step Bevel Formula:

$$\frac{(\sin \phi\,(0.5D + 4') \times 2 + \text{Total Clear Zone Width})}{\cos \phi} + (2' + 2X + H) \times 2 = \text{min. pipe length}$$

$$\frac{(\sin 12°\,((0.5 \times 18') + 4') \times 2 + (36' + 12' + 12' + 36'))}{\cos 12°} + (2' + (2 \times 4.5') + 18') \times 2$$
$$= \text{min. pipe length}$$

$$\frac{(0.2079 \times 13') \times 2 + 96')}{0.9781} + (29' \times 2) = \text{min. pipe length}$$

$$\frac{101.4054'}{0.9781} + 58' = \text{min. pipe length}$$

= 161.68', round to 162'

Quantity Summaries Example Calculations

SYMMETRICAL SECTIONS BACKGROUND

Section 13.5.1.1 provides an overview of symmetrical sections that is the most commonly used typical section for determining the horizontal dimensions of various surface courses. The first step is to establish the width of subgrade using the following equation:

$$W_S = W_f + \left(\frac{tZ}{1 - CZ}\right)$$

where:

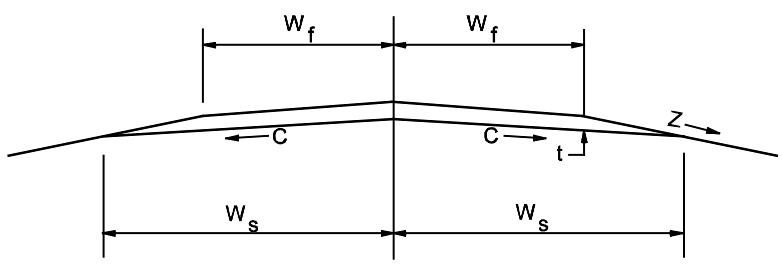
W_S = half width of subgrade, feet

W_f = half width of finished grade, feet

t = total surfacing thickness at finished shoulder, feet

Z = numerator of side slope ratio (e.g., Z = "6" for a 6:1 side slope)

C = crown, feet/feet (e.g., 0.02 for 2% cross slope)



Round the computed value for W_s to the nearest 0.1′. Because of the rounding process, the side slope through the surfacing courses will not be exactly 6:1, but the difference is negligible.

The second step is to establish the width of the intermediate surfacing courses. Compute each horizontal course dimension proportionately to its thickness. The width at the top of any surfacing course is determined by using the following equation:

$$W_X = W_f + \left[\frac{(W_S - W_f)}{t}\right] t_X$$

where:

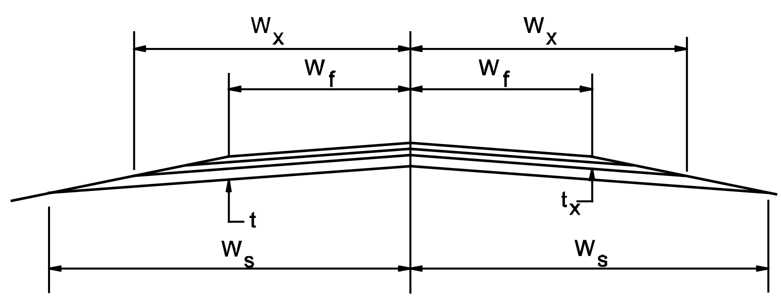
W_X = half width of top of intermediate surfacing course, feet

W_f = half width of finished grade, feet

W_S = half width of subgrade, feet

t = total surfacing thickness at finished shoulder, feet

t_X = cumulative thickness of courses above W_X at finished shoulder, feet



Round the computed value for W_X to the nearest 0.1′.

Example 13-1: Symmetrical Sections – Width of Subgrade

Given: W_f = 20.0 feet
t = 1.80 feet
Z = 6:1
C = 0.02

Problem: Determine the half width of subgrade.

Solution:

1. Use the following equation and solve for W_s.

$$W_S = W_f + \left(\frac{tZ}{1 - CZ}\right)$$

$$W_S = 20.0' + \frac{(1.8')(6)}{1 - (0.02)(6)}$$

$$W_S = 20.0' + 12.27' = 32.27'$$

$$W_S = 32.3' \text{ (Rounded to nearest 0.1 foot)}$$

The second step is to establish the width of the intermediate surfacing courses, which is shown in more detail in Example 13-2.

Example 13-2: Symmetrical Sections – Intermediate Surface Width

Given: $t_x = 0.80'$

Problem: Using the values given in Example 13-1, determine the intermediate surfacing course half width.

Solution:

1. Use the following equation and solve for W_X.

$$W_X = W_f + \left[\frac{(W_S - W_f)}{t}\right] t_X$$

$$W_X = 20.0' + \left[\frac{(32.3' - 20.0')}{1.8'}\right] 0.80'$$

$$W_X = 20.0' + 5.467' = 25.467'$$

$W_X = 25.5'$ (Rounded to nearest 0.1′)

UNSYMMETRICAL SECTIONS BACKGROUND

Section 13.5.1.2 provides an overview of unsymmetrical sections that compute and record the widths to the left and right of centerline separately for determining the horizontal dimensions of various surface courses.

Superelevated Sections.

To compute subgrade widths for superelevated sections, use the equations shown below:

Low Side

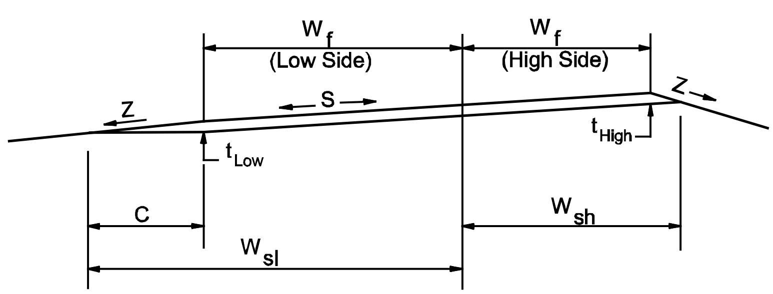
$$W_{sl} = W_f + \frac{tZ}{1-CZ}$$

High Side

$$W_{sh} = W_f + \frac{tZ}{1+SZ}$$

where:

- W_{sl} = width from centerline to edge of subgrade on low side of superelevation, feet
- W_{sh} = width from centerline to edge of subgrade on high side of superelevation, feet
- W_f = width from centerline of finished grade, low or high side, feet
- t = total thickness of surfacing at finished shoulder, feet
- S = slope of superelevation, feet/feet (e.g., 0.07 for 7% superelevation)
- Z = numerator of side slope ratio (e.g., Z = "6" for a 6:1 side slope)
- C = cross slope of tangent typical section, feet/feet (e.g., 0.02 for 2% cross slope)



Round each computed value for W_{sl} and W_{sh} to the nearest 0.1′.

Divided Highways.

For both tangent and curved sections of divided highways, compute the subgrade widths left and right of centerline as follows:

Tangent

$$W_S(median) = W_f(median) + \frac{tZ}{1-CZ}$$

$$W_S(outside) = W_f(outside) + \frac{tZ}{1-CZ}$$

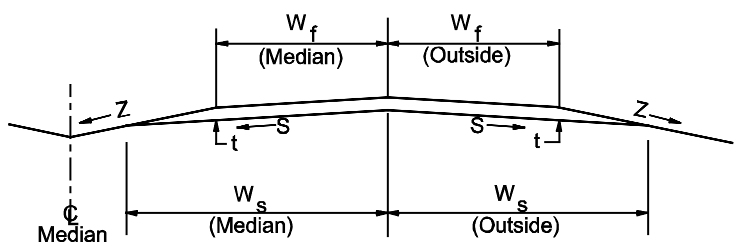
Curve

$$W_S(median\ high\ side) = W_f(median) + \frac{tZ}{1+SZ}$$

$W_S(outside\ low\ side) =$ same as tangent typical section width

$$W_S(outside\ high\ side) = W_f(outside) + \frac{tZ}{1+SZ}$$

$W_S(median\ low\ side) =$ same as tangent typical section width



Round all computed subgrade half widths to the nearest 0.1′.

Intermediate (High Side).

Compute the widths of intermediate surfacing courses for unsymmetrical sections on the high side in the same manner as for symmetrical sections (i.e., proportionately to the thicknesses), except that the width should be computed and recorded separately for each side of the centerline and rounded to the nearest 0.1′.

Intermediate (Low Side).

The following example (Example 13-3) illustrates the procedure that should be used to determine the widths for the intermediate surface courses on the low side of superelevated curves:

Example 13-3: Unsymmetrical Sections – Intermediate Surface Widths

Given: t = 1.80 feet

t_{x1} = 0.30 feet

t_{x2} = 0.50 feet

W_S = 32.3 feet

W_f = 20.0 feet

Superelevation rate = 8%

Subgrade shoulder slope = 2%

Problem: Determine the widths for the intermediate surface lifts.

Solution:

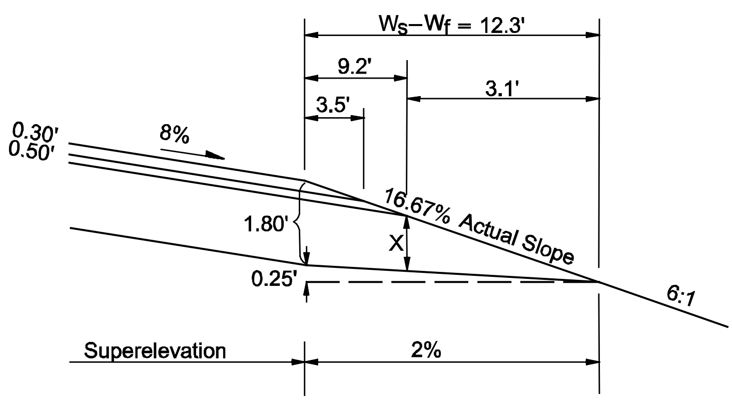
1. Determine the actual slope rate.

   Subgrade shoulder width = W_S - W_f = 12.3′

   Rise of subgrade = 12.3′ x 0.02 = 0.246′ ≈ 0.25′
   Total depth = 0.25′ + 1.80′ = 2.05′
   Actual slope = 2.05′ ÷ 12.3′ = 0.1667, or 16.67%
   (Rounded to the nearest 0.01%)

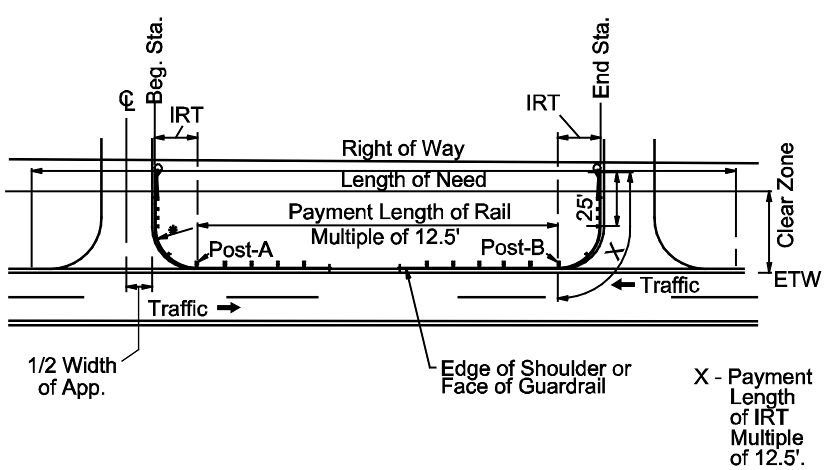
2. Determine horizontal distance for intermediate lifts.

   Slope difference = (16.67 - 8.00) ÷ 100 = 0.0867
   t_{x1} ÷ slope difference = 0.30′ ÷ 0.0867 = 3.46′ ≈ 3.5′
   (t_{x1} + t_{x2}) ÷ slope difference = (0.30′ + 0.50′) ÷ 0.0867 = 9.23′ ≈ 9.2′



GUARDRAIL QUANTITIES BACKGROUND

1. All w-beam, box beam, and cable guardrail runs are measured by the length of feet, exclusive of terminal sections or transitions. One-way departures, Optional Terminal Sections (OTS), Intersecting Roadway Terminals (IRT), and all transitions (including Bridge Approach Sections) are measured per each.
2. Lengths of w-beam guardrail should be rounded up to 12.5-foot increments, and the length of each OTS is 50 feet.
3. Lengths of box beam guardrail should be rounded up to 18-foot increments, and the length of each box beam OTS is 48.2 feet.
4. Lengths of three-strand, low tension cable rail is rounded to the nearest 0.1′ per rounding criteria, and the length of each terminal section is 26 feet. There is no standard increment for normal cable rail, although the maximum post spacing will be 16 feet or 12 feet, depending on roadway curvature. The maximum length of a run (distance between terminal sections) of low tension cable rail is 2000 feet, however multiple runs can be combined to shield longer distances. See the *MDT Detailed Drawings* for layout diagram.
5. All one-way departure sections, and low tension cable terminal sections are located entirely outside the length of need. See the *MDT Detailed Drawings* for the length of need limits within Optional Terminal Section pay limits.
6. Rounding of guardrail to standard lengths will result in lengths of full strength rail that are greater than the measured length of need. When connecting to a fixed location, such as the end of a bridge rail, the stationing called out for guardrail will need to be established based on the bridge rail stationing. For other applications, providing the additional length to the advancement side of the adjacent traffic may be the best practice, however the location of approaches or other roadside features may dictate the optimum location. So long as the entire length of need is protected by full strength rail, and the rail length is at a standard increment, the end stations are not critical for these installations.
7. If approaches, turnouts or other obstacles are within the required length of w-beam guardrail, IRT terminals may be used to shorten the required length. IRTs do not meet all current crash testing requirements, and should only be used as a best practical remaining alternative where fully compliant roadside hardware cannot address a guardrail warrant.



a. Ensure that the right-of-way width is sufficient (i.e., far enough from the shoulder to get the full IRT installed without encroaching onto private property). The width required from the edge of the roadway (face of rail) to the R/W line is equal to the IRT radius + 26.5 feet.

b. Determine the best fit IRT radius based on the approach radii, R/W availability, and the location requirements of the normal run of w-beam. Minor adjustments to the approach stationing or minor grading along the edge of the approach may be necessary to fit the IRT to the approach without impacting turning movements or extending beyond the R/W limit.

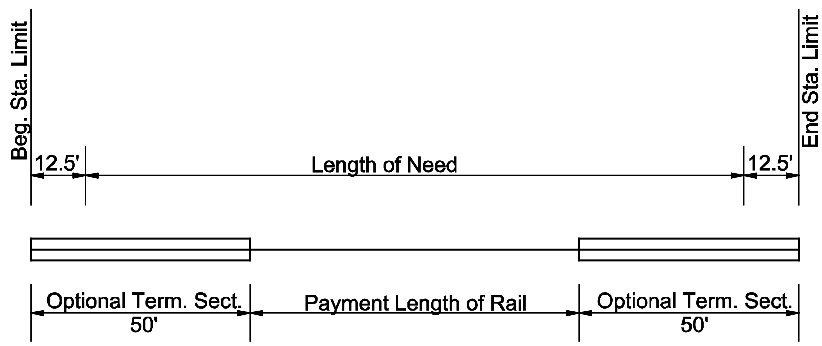
c. The end anchors are included in the IRT bid item.

d. The following table lists available IRT radii and associated pay limits:

Radius	Length of Bent Rail	Total Length of IRT (pay limits)
8'	12.5'	37.5'
16'	25.0'	50.0'
24'	37.5'	62.5'
32'	50.0'	75.0'

Example 13-4: W-Beam Guardrail

Given: W-beam guardrail is warranted between Stations 9+90 and 15+00 on the left side of a two-way roadway. There are no roadway approaches or other features that influence the guardrail location.



Problem: Determine the beginning and ending stations and the length of rail for payment.

Solution:

1. [15+00.00] – [9+90.00] = 510.00′ actual length of need

2. 510.00′ ÷ 12.5′/section = 40.8 sections, Round $\Rightarrow$ 41

3. 41 x 12.5′ = 512.50′ Length of need based on minimum standard increment

4. Per the detailed drawings, 37.5′ of each OTS provides full strength for length of need.

5. 512.50′- 2(37.50′) = 437.5′ length of standard run rail

6. In this case, no features have been identified to restrict guardrail placement. Locate the guardrail to provide the additional length on the advancement side of the adjacent traffic. Since the rail is on the left side of the roadway, adjacent traffic is moving opposite the direction of increasing stationing, therefore start the calculation from the lower station value:

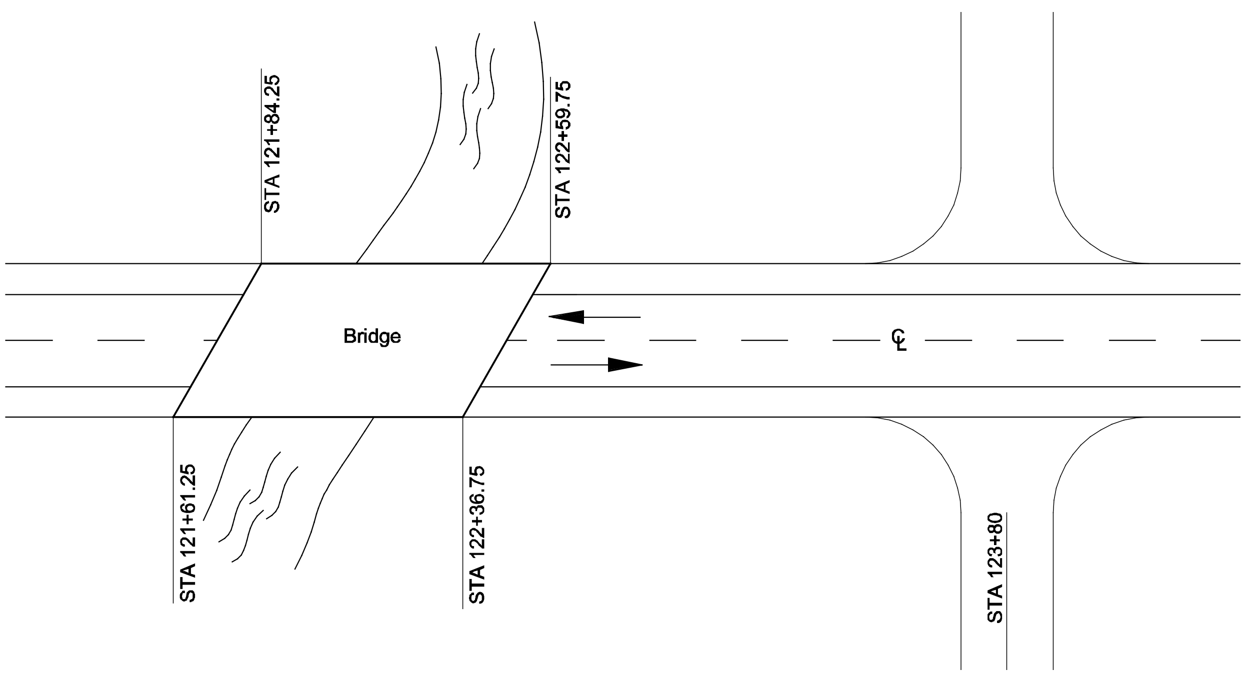
   [9+90.00] - 12.50′ (the portion of the OTS outside of the length of need)
   = 9+77.50 Beginning Station

   [9+77.50] + 437.50′ w-beam + (2 x 50′ OTS)
   = 15+15.00 Ending Station

Additional discussion: If the rail had been on the right side, providing the additional length on the advancement side of the adjacent traffic would be calculated from the end station of the length of need working back on stationing (15+12.50 back to 9+75.00).

Example 13-5: Computations of Pay Quantities for W-Beam Guardrail and Intersecting Roadway Terminal (IRT) Sections

Given: A bridge replacement project (on a two-way, two-lane highway) calls for guardrail lengths of need from the end of the bridge rail of 141.5 feet and 76.2 feet, for the approach and departure sides respectively. (See Example 9-3). The roadway width is 40 feet (12 foot lanes and 8 foot shoulders) and R/W is 80 feet from centerline on each side of the road. There are private approaches needed on each side of the roadway at station 123+80. The approaches are currently designed 24 feet wide with 25 foot radii per *MDT Detailed Drawings* and cannot be relocated beyond minor adjustments.



Problem: Determine appropriate w-beam guardrail treatment for the end of the bridge with the private approaches, and determine the station limits and quantities for the guardrail.

Solution:

1. Determine the appropriate treatment for the bridge approach rail connecting to the bridge rail on the right side:

   Calculate the available distance from the end of the bridge rail to the beginning of the approach radius.

   Approach station [123+80.00] – 12′ half approach width – 25′ radius = begin of radius station [123+43.00]

   Begin of radius station [123+43.00] – end of bridge rail station [122+36.75] = 106.25′ of available space.

Divide the departure length of need by the standard increment to determine the full strength guardrail needed.

76.2′ ÷ 12.5′/section = 6.096 sections, Round ⇒ 7 sections of rail for length of need

Since the last 12.5′ of a W-beam OTS is not full strength, add 12.5′ to the needed guardrail length.

(7 sections x 12.5′/section) + 12.5′ = 100.0′

100.0′ of needed guardrail < 106.25′ of space available, therefore use standard w-beam approach rail with a Bridge Approach Section and OTS.

The guardrail on the right side will be from station 122+36.75 to 123+36.75 and will include one 25-foot Bridge Approach Section (bid per each), one 50-foot OTS (bid per each), and 25 feet of w-beam.

2. Determine the appropriate treatment for the bridge approach rail connecting to the bridge rail on the left side:

Calculate the available distance from the end of the bridge rail to the beginning of the approach radius.

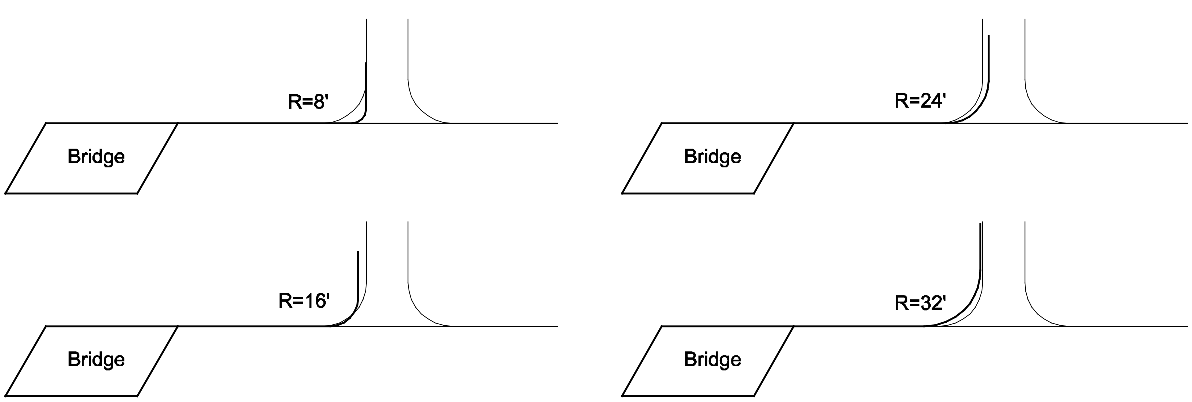
Begin of radius station [123+43.00] – end of bridge rail station [122+59.75] = 83.25′ available. This distance is long enough to allow the minimum length of blunt end protection with an OTS for the bridge end (25′ Bridge Approach Section and 50′ OTS). However, this option does not provide the calculated advancement length needed for shielding the crossing hazard.

Determine a bridge approach rail solution using an IRT:

The edge of the current approach station is [123+80.00] – 12′ half width of approach = [123+68.00]

The space for rail with an IRT = [123+68.00] - [122+59.75] = 108.25′

IRT radii are available in increments of 8 feet, up to 32 feet. Subtracting each radius from the space available leaves available lengths of tangent guardrail of 100.25′, 92.25′, 84.25′, and 76.25′. The closest fit configuration for each IRT radius option is shown below (approach end is at the R/W limit for all cases).



For this example, all options fit within the available R/W and could potentially be used with minor widening, narrowing, and/or relocation of the approach location. In this instance, the 24 foot radius was selected (with the approach being relocated 4 feet ahead on station), based on the anticipated traffic needs. Selecting this option does not require any additional width in guardrail widening in front of the rail or a reduction in approach radius. It also provides nearly 10 feet of space between the R/W line and the end of rail for maintenance/utility access.

Determine stationing:

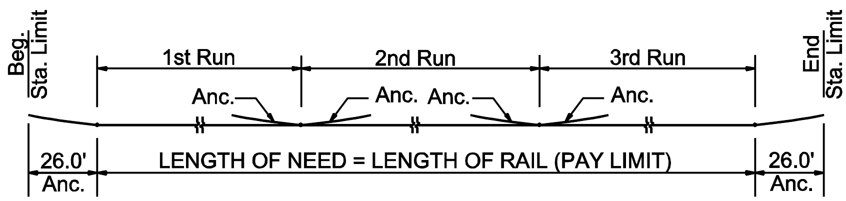
[122+59.75] + 25' (bridge approach section) + 62.5' (normal run w-beam) + 24' (IRT radius) = [123+71.25]

The guardrail on the left side will be from station 122+59.75 to 123+71.25 and will include one 25-foot Bridge Approach Section (bid per each), 62.5 feet of normal run w-beam, and 62.5 feet of Intersecting Roadway Terminal.

Example 13-6: Cable Guardrail

Given: Low-tension cable guardrail is warranted between Station 20+00 and 75+00.

Problem: Determine the beginning and ending stations for the cable rail, the length of rail for payment, and the number of terminal sections needed and measured for payment.



Solution:

1. [75+00.00] – [20+00.00] = 5,500.0′ feet of cable rail measured for payment

2. 5,500.0′ ÷ 2000′ (maximum run length) = 2.75, Round ⇒ 3 runs of rail needed

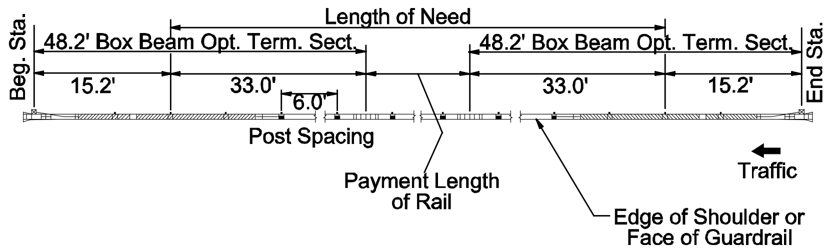
3. Two terminal sections are needed per run of rail:

   3 runs x 2 terminals/run = 6 terminal sections needed (bid per each)

4. [20+00.00] – 26′ terminal section length = 19+74.00 Beginning Station
   [75+00.00] + 26′ = 75+26.00 Ending Station

Example 13-7: Box Beam Guardrail

Given: Box Beam guardrail is warranted between Stations 17+50.00 and 32+75.00. The facility is a two-lane, two-way roadway requiring an Optional Terminal Section (OTS) at each end, and there is a private approach at station 33+40 on the same side of the roadway as the guardrail.



Problem: Determine the beginning and ending stations and the length of rail for payment.

Solution:

1. [([32+75.00] – [17+50.00]) - (2)(33.0′ of full strength rail per OTS)] ÷ 18′ increment = 81.06 sections, Round $\Rightarrow$ 82 sections of Box Beam guardrail

2. 82 x 18′ = 1,476.0′ Payment Length of Box Beam Guardrail

3. Because of the approach located at station 33+40, locate the rail as far back on stationing as possible to reduce impacts to sight distance and turning maneuvers associated with the approach.
   [32+75.00] + 15.2′ of OTS outside of length of need = 32+90.20 Ending Station
   [32+90.20] - 1476.0′of standard run rail - (2 x 48.2′ OTS length) = 17+17.80 Beginning Station

4. 2 Box Beam Optional Terminal Sections bid per each

Example 13-8: Finish Grade Control

Given: 4-lane freeway with 7 miles of construction
Interchange with construction of four 0.4 mile long ramps
2-lane intersecting roadway with 1 mile of construction

Pavement section:

0.30′ Plant Mix
1.20′ Crushed Aggregate Course
2.00′ Special Borrow

Problem: Determine the amount of finish grade control staking required for the project.

Solution: Calculate the course mile of finish grade control staking for the mainline, ramps and intersecting roadway (round up to nearest 50-foot increment):

2 x 7.0 mile = 2 x 36,960′, rounded to 2 x 37,000′ = subgrade for mainline	74,000 feet
2 x 7.0 mile = special borrow for mainline	74,000 feet
2 x 7.0 mile = crushed aggregate for mainline	74,000 feet
4 x 0.5 x 0.4 mile = 4 x 0.5 x 2,112′, rounded to 4 x 0.5 x 2,150′ = subgrade for ramps	4,300 feet
4 x 0.5 x 0.4 mile = special borrow for ramps	4,300 feet
4 x 0.5 x 0.4 mile = crushed aggregate for ramps	4,300 feet
1.0 mile = 5,280′, rounded to 5,300′ = subgrade for intersecting road	5,300 feet
1.0 mile = special borrow for intersecting road	5,300 feet
1.0 mile = crushed aggregate for intersecting road	5,300 feet
	250,800 feet total

APPROACH GRADING BACKGROUND

Approach grading will be paid the same as the mainline grading, (i.e. Unclassified Excavation or Embankment in Place), as further described in Chapter 13 - Quantity Summaries. Approach fills within the clear zone will be 10:1, regardless of fill height. This does not apply where the approach is shielded with guardrail. See the *MDT Detailed Drawings* for all approach grading information.

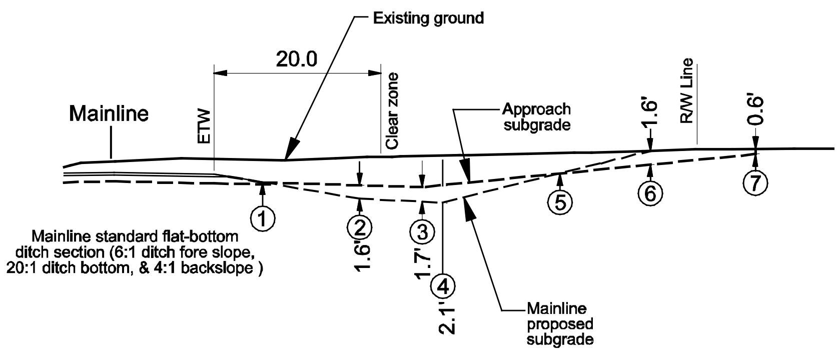
Earthwork quantities for approaches can be calculated using several appropriate methods, including three-dimensional (3D) modeling, not all of which are covered here. It is important to note that as the complexity, or importance of an approach increases, so should the level of design increase. For approaches with major realignment (e.g., button hook approaches), substantial changes in grade, or other unique design features, more detailed earthwork calculations may be necessary. It is recommended that the same method that was used to generate the mainline quantities be used on these approaches. Details including plan and profile should be provided for public approaches, as well as the private or farm field approaches requiring significant design work.

Two example methods for calculating approach grading quantities on approaches not requiring significant design work will be outlined in the following sections. The first method of calculation utilizes tabulated end areas and should cover the most common approaches being designed and will work for approaches in both cut or fill sections. The second method is only for very basic approaches with minimal grading impact to mainline grading, and where the approach grading is in a fill section compared to either existing ground or proposed mainline grading.

Example 13-9: Approach Grading – Method 1, Tabulated End Areas

1. **Procedure**.
   a. This procedure uses the mainline cross section that was taken at the centerline of the approach. Therefore, ensure that the approach is accurately drawn in the cross section. Method 1, as demonstrated, would not be appropriate for approaches with a severe skew.
   b. Steps "c" thru "f" follow the Approach Earthwork Example Calculation, shown below.
   c. Measure the horizontal distance from the intersection of the mainline surfacing inslope and the approach subgrade ① to each distinct grade break on the existing ground or proposed mainline subgrade line ②,③,④,⑥, & ⑦, and cut/fill transition points ⑤. This distance is entered as a "Station" in the Earthwork Computation Form (see table below). Only distinct/abrupt grade breaks that the design team believes affect the accuracy of earthwork quantity need to be measured.
   d. Measure the vertical distances at each point determined in Step "c".
   e. Use the vertical distance to obtain an area from the Approach Grading Quantities tables, shown below. It is recommended that the design team interpolate the end area values from the actual vertical distances obtained in Step "d" (interpolated values used in the Approach Earthwork Example Calculation, shown below). The values provided are based on a standard approach with a 34-foot wide subgrade (see *MDT Detailed Drawings*).
   f. Complete the Earthwork Computation Form (see table below). Adjustments (shrink/swell factors) to the Excavation and Embankment quantities should be made when entering the quantities into the mainline grading. The adjusted values for the approach grading quantities obtained from the mainline grading should be the values entered in the plans (i.e., Additional Grading Summary Frame & Cross Section Sheets).

APPROACH EARTHWORK EXAMPLE CALCULATION

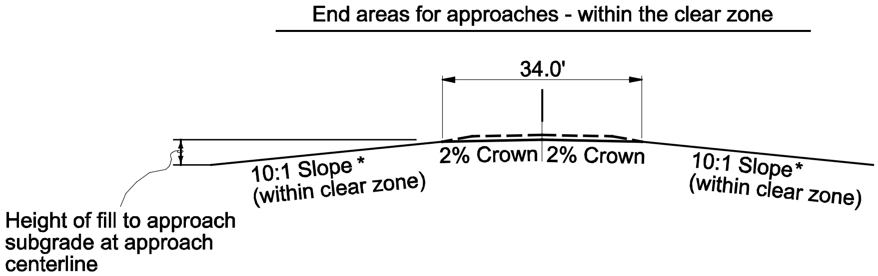


EARTHWORK COMPUTATION FORM

STATION	DIST. (ft)	AREAS IN SQUARE FEET				VOLUMES IN CUBIC YARDS					
		CUT		FILL		EXCAVATION			EMBANKMENT		
		AREA	DOUBLE AREA	AREA	DOUBLE AREA	ACTUAL	SWELL FACTOR	ADJ. EXC.	ACTUAL	SHRINK FACTOR	EMB. +
0+00.0		0		0							
	11.6		0		65.2	0			14		
0+11.6		0		65.2							
	7.5		0		125	0			17		
0+19.1		0		59.8							
	2.5		0		137.8	0			6		
0+21.6		0		78.0							
	14.1		0		78	0			20		
0+35.7		0		0							
	10.9		109.4		0	22			0		
0+46.6		109.4		0							
	12.5		132.8		0	31			0		
0+59.1		23.4		0							
					TOTAL	**53**		*	**57**		*

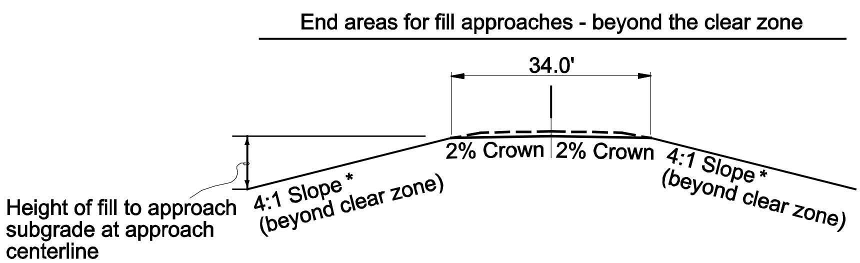
* VALUES SHOULD BE ADJUSTED AT THE SAME RATE AS MAINLINE. MAKE ADJUSTMENT WHEN ENTERING QUANTITIES INTO MAINLINE GRADING.

APPROACH GRADING QUANTITIES



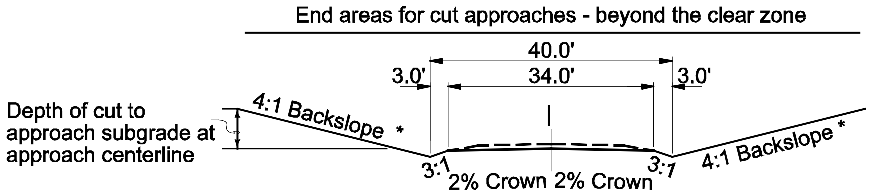
10:1 FILL SLOPE	
HEIGHT OF FILL (FT.)	AREA (SQ. FT.)
0.5	11
1	33
1.5	59
2	90
2.5	126
3	167
3.5	213
4	264
4.5	320
5	381

10:1 FILL SLOPE	
HEIGHT OF FILL (FT.)	AREA (SQ. FT.)
5.5	447
6	519
6.5	595
7	676
7.5	762
8	853
8.5	949
9	1050
9.5	1156
10	1267



4:1 FILL SLOPE	
HEIGHT OF FILL (FT.)	AREA (SQ. FT.)
0.5	11
1	30
1.5	51
2	73
2.5	98
3	125
3.5	153
4	184
4.5	216
5	251

4:1 FILL SLOPE	
HEIGHT OF FILL (FT.)	AREA (SQ. FT.)
5.5	288
6	326
6.5	367
7	410
7.5	454
8	501
8.5	550
9	600
9.5	653
10	707



4:1 BACKSLOPE	
DEPTH OF CUT (FT.)	AREA (SQ. FT.)
0.5	44
1	73
1.5	103
2	135
2.5	170
3	206
3.5	245
4	285
4.5	327
5	372

4:1 BACKSLOPE	
DEPTH OF CUT (FT.)	AREA (SQ. FT.)
5.5	324
6	359
6.5	394
7	430
7.5	467
8	505
8.5	544
9	585
9.5	626
10	668

Example 13-10: Approach Grading – Method 2, Basic Fill Approach Grading

1. **Procedure**.

   a. This procedure uses the mainline cross section that was taken at the centerline of the approach. Therefore, ensure that the approach is accurately drawn in the cross section. Method 2 is only appropriate for use on approaches with minimal grading impacts to mainline grading, and where the approach grading is in a fill section compared to either existing ground or proposed mainline grading.

   b. Steps "c" thru "f" follow the Basic Fill Approach Grading Example, shown below.

   c. Measure the fill area between the proposed slopes or existing ground (whichever is appropriate) and the approach subgrade.

   d. Multiply the measured area of fill by the width of the approach and then convert to cubic yards. This will estimate the volume of the central 24 feet of the approach.

      Example fill volume for central 24 feet of approach:

      (30.5 sq. ft. x 24.0 ft.)/(27 cu.ft./cu. yd) = 27.1 cu. yds.

   e. Estimate the approach fill slope volume by multiplying the height at the mainline ditch (fill catch) by the length of fill by the slope rate (4:1 = 4), then convert to cu.yds. Using this method will average both left and right of mainline at the same volume. Additionally, with this method it is not necessary to make a separate calculation for the 10:1 slopes inside of the clear zone.

      Example fill volume for approach slope grading (LT. & RT.):

      (1.5 ft. x 37.7 ft. x 4 ft./ft.)/(27 cu.ft./cu.yd.) = 8.4 cu. yds.

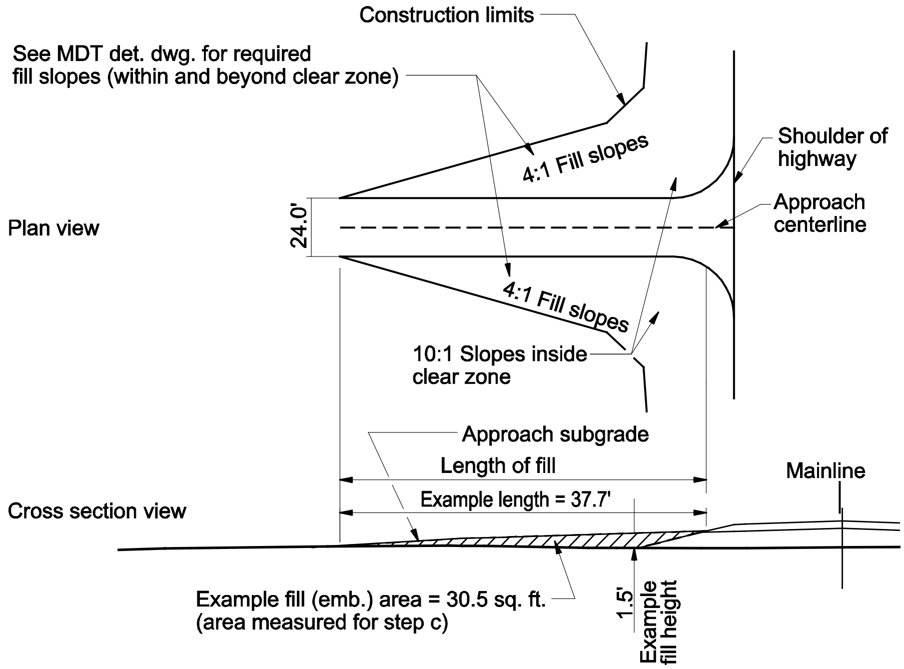
   f. Sum the estimated volumes from the approach's central 24 ft. (from Step "d") and the approach slope grading (from Step "e").

      Example total approach fill (EMB.) volume:

      27.1 cu.yds. + 8.4 cu.yds. = 35.5 cu.yds.

   g. If the grading pay item is Unclassified Excavation (UNCL. EX.), then adjust (shrink/swell) Embankment (EMB+) quantities in the same manner as done for the mainline. Make the adjustment when entering quantities into the mainline grading. The adjusted values for the approach grading quantities obtained from the mainline grading should be the values entered in the plans (i.e., Additional Grading Summary Frame & Cross Section Sheets).

BASIC FILL APPROACH GRADING EXAMPLE



Example 13-11: Topsoil Replacement Quantities

Given: A rural reconstruction project, utilizing unclassified excavation with 20% shrink and with the following topsoil and seeding quantities:

TOPSOIL & SEEDING											
STATION		cubic yards	acres							square yards	REMARKS
		TOPSOIL SALVAGING & PLACING	SEED			FERTILIZER		CONDITION SEEDBED	MULCH	EROSION CONTROL BLANKET (LONG-TERM)	
FROM	TO		NO. 1	NO. 2	NO.3	NO. 1	NO. 2				
53+81.86	83+00.00	1,450	4.4	2.0	0.2	4.4	2.0	4.6	2.0		
83+00.00	113+00.00	2,348	0.2	6.2	2.1	0.2	6.2	2.3	6.2		
93+52.02	94+01.48									106	BRIDGE END GRADING EROSION CONTROL
113+00.00	143+00.00	721	0.3		1.0	0.3		1.3			
143+00.00	170+19.65	767	5.2		1.5	5.2		6.7			INCLUDES CONNECTION TO PTW
TOTAL		5,286	10.1	8.2	4.8	10.1	8.2	14.9	8.2	106	

Problem: Determine the topsoil replacement quantities.

Solution: Topsoil replacement is a grading quantity that is needed to adjust the earthwork on a project to account for the topsoil that is salvaged from the roadway construction limits prior to the general grading operation. This material was in place when the project was surveyed and the digital terrain model (DTM) was created, and is included in the line representing the existing ground to which cut and fill quantities are measured. The removal of this material prior to grading has the effect of lowering the existing ground line wherever it is removed, thereby underestimating the amount of embankment needed in fill sections, and overestimating the amount of material generated from cut sections. For either condition, embankment material must be added to the earthwork run to account for the topsoil that is removed.

To estimate the amount of embankment required for topsoil replacement, the quantity of topsoil salvaged needs to be adjusted by the project shrink factor. The Standard Specifications require that the contractor salvage enough topsoil from within the construction limits to dress the finished slopes with four inches of topsoil. For this reason, the depth, quality and distribution of the topsoil on the existing slopes is somewhat irrelevant. Similarly, areas where topsoil is not removed (e.g. Foundation Treatment areas) do not typically need special consideration when calculating Topsoil Salvaging and Placing quantities. The Topsoil Salvaging and Placing quantities have already been calculated for this example and are indicated in the summary frame above. Although the Summary is Topsoil & Seeding, the quantity splits are intended to aid in calculating topsoil replacement grading quantities, and to show the distribution of these quantities more uniformly in the mass diagram and earthwork run.

Since grading on this project is measured as Unclassified Excavation, an earthwork run and mass diagram are developed. The unadjusted quantities of topsoil salvage should be entered into the earthwork run as point additional embankment quantities for each section, and adjusted according to the project shrink factor. It isn't critical whether the "from" or "to" station is used to identify the locations where these quantities are added in the earthwork run, only that the method used is consistent for the project.

ADDITIONAL GRADING					
STATION		cubic yards			REMARKS
		INCL. IN ROADWAY		ADD. UNCL. EXC.	
FROM	TO	UNCL. EXC.	EMB.+		
53+81.86	83+00.00		1,740		TOPSOIL REPLACEMENT
60+91.00		15	230		FARM FIELD APP. RT.
61+78.00	64+63.90	*	*		MAILBOX TURNOUT LT.
63+08.00		25	5		PRIVATE APP. LT.
69+26.00	72+12.00	*	*		MAILBOX TURNOUT RT.
70+83.00		30	80		PRIVATE APP. RT.
78+77.00		15	70		PRIVATE APP. LT.
81+11.44	81+87.56		5		G-RAIL OTS EMB. WIDENING RT.
82+60.65	83+36.77		25		G-RAIL OTS EMB. WIDENING LT.
83+00.00	113+00.00		2,818		TOPSOIL REPLACEMENT
93+25.02	93+50.02		65		G-RAIL BRIDGE APPROACH SECTION WIDENING LT.
93+25.02	93+50.02		10		G-RAIL BRIDGE APPROACH SECTION WIDENING RT.
93+52.02	94+01.48	930	10		BRIDGE END GRADING - SEE DETAIL
94+03.48	94+28.48		25		G-RAIL BRIDGE APPROACH SECTION WIDENING LT.
94+03.48	94+28.48		50		G-RAIL BRIDGE APPROACH SECTION WIDENING RT.
93+87.00		15			DRAINAGE DITCH - SEE BRIDGE END GRADING DETAIL
96+15.98	96+92.10		5		G-RAIL OTS EMB. WIDENING LT.
99+27.00		50	5		PRIVATE APP. LT. - 48' WIDE
101+40.98	102+06.85		45		G-RAIL OTS EMB. WIDENING RT.
102+35.00		80	520		PRIVATE APP. RT.
107+00.00		170			PRIVATE APP. LT.
113+00.00	143+00.00		865		TOPSOIL REPLACEMENT
119+98.88	120+75.00		5		G-RAIL OTS EMB. WIDENING LT.
142+47.25	143+07.74		45		G-RAIL OTS EMB. WIDENING RT.
143+00.00	170+19.65		920		TOPSOIL REPLACEMENT
143+25.00		225	15		FARM FIELD APP. RT. - 12' WIDE
147+95.00		300			FARM FIELD APP. RT. - 12' WIDE
150+75.00	151+51.12		5		G-RAIL OTS EMB. WIDENING LT.
153+30.00		10	2,610		PRIVATE APP. LT. (MT DNRC)
155+79.50	156+55.62		5		G-RAIL OTS EMB. WIDENING RT.
163+66.00	166+50.00	*	*		MAILBOX TURNOUT LT.
SUBTOTAL		~	~	~	

Note: # EXCAVATION QUANTITIES-MATERIAL UNSUITABLE FOR ROADWAY EMBANKMENTS

* INCLUDED IN MAINLINE GRADING

Additional discussion: For projects measuring grading as Embankment-in-Place, the entire quantity of topsoil salvaged is identified on a separate line of the Grading Frame, and identified as "TOPSOIL REPLACEMENT" in the Remarks column. For these projects, no adjustments to grading are made, and additional grading items are not included in the earthwork run.