MONTANA MDT DEPARTMENT OF TRANSPORTATION

SURVEY MANUAL

January 2024

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INTRODUCTION

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CHAPTER 1 | INTRODUCTION

1.1 Introduction

This manual was developed to provide statewide uniformity in surveying practices, to establish and maintain survey standards, and to improve the overall efficiency of the Montana Department of Transportation's (MDT) survey function. Both MDT personnel and consultants retained by the MDT should adhere to the standards, procedures, and specifications given in this manual. The engineering project manager (EPM), the consultant, or the land surveyor should ensure their surveys conform to this manual. For the purpose of this manual, the term "survey crews" refers to both MDT employees and their agents.

If the surveying requirements of this manual conflict with the requirements of contract documents, then the contract prevails.

All survey work performed for MDT shall conform with current statutes in Montana Code Annotated and current rules in the Administrative Rules of Montana.

1.1.1 Description of Surveying

Surveying is performed to determine the relative positions of points on or near the earth's surface. It involves making measurements and calculations to provide essential information needed for planning highway routes, acquiring land, designing and constructing highways, and other related activities.

1.1.2 Chapter Summaries

The *MDT Survey Manual* is organized into eight chapters and three appendices.

Chapter 1: Introduction. Establishes the purpose of the *MDT Survey Manual* and explains its organization. Includes information regarding public relations, right of entry, safety, and the effective date.

Chapter 2: Coordinate Systems and Datums. Addresses the datums and systems used as references for surveys, including vertical and horizontal datums, the Montana State Plane Coordinate System, and other related topics.

Chapter 3: Equipment. Identifies surveying equipment commonly used for MDT projects. Includes guidance on common errors to avoid and care for equipment, including guidance on required baseline calibration reports.

Chapter 4: Control Surveys. Describes planning and execution of establishing new project control, new aerial control, secondary control, and reset control. Provides guidance on control monumentation and locations. Provides control standards and a list of deliverables.

Chapter 5: Engineering Surveys. Describes standards and procedures for developing topographic mapping surveys to support engineering design functions. Includes large section with specific collection requirements for hydraulic surveys. Includes a list of deliverables.

Chapter 6: Cadastral Surveys. Describes the purpose and requirements of cadastral surveys, the involvement of the land surveyor, and deliverables.

Chapter 7: Remote Sensing. Describes standards for developing remotely sensed mapping data from photogrammetric and lidar sensors. Lidar point cloud guidance encompasses terrestrial, mobile, and aerial lidar. Includes requirements for both use of unmanned aerial vehicles (UAVs) and manned aircraft to develop mapping products. Provides a list of required deliverables.

Chapter 8: Construction Surveys. Covers survey methods, preconstruction control, perpetuation of NGS bench marks, right-of-way monumentation, clearing and grubbing, earthwork, bridge surveys, drainage facilities, and curb and gutter staking.

Appendices: Cover the subjects as indicated by their titles:

- Appendix A: Glossary. Definitions, abbreviations, and conversions.
- Appendix B: Triangles. Solutions of right and oblique triangles.
- Appendix C: Curves. Circular, spiral, and vertical curves.

1.1.3 MDT File Names

MDT uses a naming structure for all electronic project files. Figure 1-1 shows a sample file name for a file required for control surveys. The Series No. (Z01) identifies it as the first file of that document type created by consultants; sample file names included herein often use Z01 for the series number, but the series number for an MDT-generated file would be different. For complete information on file names, see the current version of MDT's Project Content Management System Document Naming Standards.

MDT uses a naming structure for all electronic project files. Subsequent individual chapters provide sample file names for survey deliverables.

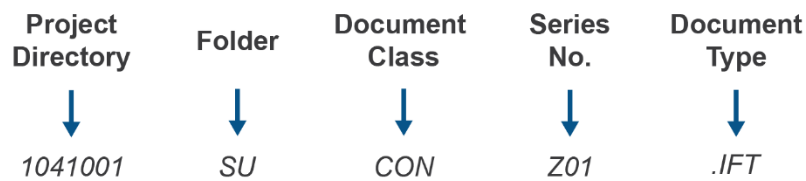

Figure 1-1: MDT document naming standards sample file

1.2 Maintenance and Updating of Manual

Everyone who has access to this manual should review the content and format and submit recommendations for improvements. The primary intent is to provide all survey crews with standard procedures. All persons should feel free to make suggestions. These suggestions will improve future editions. This manual will be updated periodically to keep it current. The suggestions should be submitted with any accompanying drawings or notes via email to the Photogrammetry and Survey Section supervisor and the land survey manager.

1.3 Assistance

For assistance or answers to questions concerning interpretation of the manual, contact the Photogrammetry and Survey Section prior to the survey. Contact the Photogrammetry and Survey Section or the district land surveyors for assistance concerning general survey questions.

For consultant projects, a survey scoping meeting is typically held to begin each project. Survey scoping meetings are the ideal time to discuss project challenges and confirm survey requirements. Chapters 4 - 8 all have additional information about how to prepare for a survey scoping meeting as it pertains to control, engineering, cadastral, remote sensing, and construction surveys.

1.4 Public Relations

1.4.1 Importance

The MDT is a public service organization, and each of its employees and consultants are representatives of MDT. Relationships with the public, property owners, media, utility and railroad companies, governmental agencies, contractors, and fellow workers can have a beneficial or adverse effect upon a project.

Survey crews are one of the most visible groups representing the MDT, and their conduct on the job and contacts with the public, property owners, and media representatives are of extreme importance in the maintenance of good public relations. Survey crews should strive to cultivate good relationships and do their best to avoid antagonistic encounters.

1.4.2 Right of Entry

Prior to entry on private land, survey crews should obtain written permission, to the extent possible, from either the owner of record and/or the lessee of the property. The original signed form will be retained in the district's preliminary engineering file. The signed form will be scanned into a PDF document and placed on the Project Content Management System (PCMS). Consultants will provide Consultant Design the original signed form. Prior to entry on the property, it is good practice to speak with landowners even if they returned a letter.

Letter responses may have special instructions, such as contacting a landowner at a certain phone number to enter a property or access by walk-in only. If access to a property needs to occur one year or longer after receiving the original letter, another letter should be sent to gain access. If permission is not granted, neither MDT representatives nor their agents should enter a property unless the survey crews comply with statutes enabling limited access such as Montana Code Annotated §§ 70-16-111 and 70-30-110. Rather, they should speak with MDT and the operations engineer to discuss the next steps to be taken to complete the project's objectives.

Work performed near railroad tracks and within the railroad right-of-way requires safety training and coordination with the railroad in control of the line.

Work performed around railroad tracks and within railroad right-of-way requires safety orientation and coordination with the railroad controlling the line.

Work performed on reservations requires coordination with the tribal government of the project area.

1.4.3 Property Owners

During survey activities, the survey crews often have day-to-day contact with the landowner. The survey crews should strive to maintain the best possible working relationships with property owners. Prior to any surveying activity, every crew member should know who the project manager is and how to contact them if a landowner needs more detailed explanation of the project. The project design manager is listed in the survey request form.

Most of the questions a survey crew is asked can be anticipated and discussed beforehand with the entire crew. The answers should always be as concise as possible without speculation or guesswork. The survey crew or their supervisor should ensure an adequate answer is given to a landowner's question as soon as practical.

1.4.4 Media

It is not the responsibility of the survey crews to discuss MDT business with the media. If approached by media representatives, refer them to the district office. Throughout any contacts with media representatives, survey crews should conduct themselves in such a manner as to maintain a good impression of MDT.

1.5 Safety

MDT has established safety standards in the workplace. These standards are for the protection of MDT employees, their agents, and the traveling public. Applicable safety guidance, policies, and procedures for the type of work being performed should be reviewed prior to beginning any work.

1.6 Signing for Survey Crews

MDT requires signing when conducting surveys on or near roadways. For signing guidelines, refer to the appropriate sections of the *Manual on Uniform Traffic Control Devices*, current MDT detailed drawings, and other appropriate MDT policies.

1.7 Effective Date

The requirements contained in this manual will become effective upon MDT approval and publication. The most current version of the *MDT Survey Manual* should be obtained prior to beginning any survey activities.

Projects having certain phases of preliminary surveys completed will adhere to the *MDT Survey Manual* in effect at the time of that survey. All new surveying activities will adhere to the requirements contained in the most current version of the *MDT Survey Manual*.

1.8 References

This manual is not intended to be used as a substitute for surveying textbooks, other policies, or standards from other disciplines, including but not limited to, the Bridge, Road Design, Hydraulics, Environmental, and Traffic and Safety bureaus. References specific to survey can be accessed through the Survey Project Development site. Below is a list of references specific to survey:

- The MDT Survey Summary Guidance document provides activity descriptions for survey projects and their core requirements, including a list of deliverables.
- The MDT Cadastral Feature Codes Reference Sheet is a document showing common feature codes for cadastral surveys.
- The Feature Code Summary is a document providing a detailed description of individual feature codes for engineering surveys.
- The Feature Code Reference Sheet is a single sheet showing common codes for engineering survey features.
- Downloadable feature files specific to MDT engineering and cadastral surveys are designed to be plugged into specific software platforms.

CHAPTER 2

COORDINATE SYSTEMS AND DATUMS

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CHAPTER 2 | COORDINATE SYSTEMS AND DATUMS

2.1 Introduction

Successful Montana Department of Transportation (MDT) projects require uniform application of coordinate systems, datums, and units by all staff collecting or using geospatial data in all phases of the project. Beyond surveyors, all members of a project team benefit from an understanding of these items and how they fit together. Datums and coordinates frequently have changed as geographical positioning systems (GPS or GNSS) technology has advanced and the demand for accuracy has increased. These changes will continue in the near future with the retirement of the United States (U.S.) survey foot, the North American Datum of 1983 (NAD83), and the North American Vertical Datum of 1988 (NAVD88). Mapping professionals should monitor the National Geodetic Survey (NGS) to track the rollouts of these significant changes.

2.2 Units

Existing projects should use whichever units the project previously has used unless a clear benefit exists from changing units. Almost all 21st century projects to date have used international feet for horizontal units and U.S. survey feet for vertical units.

At some point, MDT may adopt international feet for both horizontal and vertical units to conform with the NGS's deprecating, or retiring, of the U.S. survey foot. International feet should be used for horizontal units for all new projects; confirm vertical units during the survey scoping meeting.

Improper software settings and mishandling of import or export units between international feet and U.S. survey feet are potential sources of error with consequences amounting to multiple feet difference in application.

Surveyors should be wary of the two definitions of the foot historically used in a mixed fashion on a state-by-state basis throughout the U.S. An international foot, the future sole foot in the United States, is defined as 0.3048 meter. The U.S. survey foot, an earlier definition from previous standardization efforts, is defined as 1200/3937 meters. In small amounts, the difference between the two definitions is insignificant, but when points are expressed as coordinates in large area coordinate systems like Montana's, the difference can amount to multiple feet. Table 2.1 shows bench marks in Missoula, Helena, Billings, and Sidney with their State Plane Coordinate System coordinate values expressed in feet and their respective NAD83-2011 geodetic values.

LOCATION	NGS BM	NAD83 LATITUDE	NAD83 LONGITUDE	MTSPC NORTHING ift	MTSPC EASTING ift	MTSPC NORTHING sft	MTSPC EASTING sft	Δ N (ift-sft)	Δ E (ift-sft)
NEAR MISSOULA	SHEEP	46º 56' 51.66412" N	113º 48' 25.14738" W	1013032.53	893938.24	1013030.50	893936.46	2.0	1.8
NEAR BOZEMAN	MOUNT ELLIS	45º 34' 38.67987" N	110º 57' 21.23304" W	487473.88	1595820.89	487472.91	1595817.70	1.0	3.2
NEAR BILLINGS	SALZY	45º 44' 04.63323" N	108º 24' 01.13160" W	543287.73	2249205.58	543286.64	2249201.09	1.1	4.5
NEAR SIDNEY	MONDAK	48º 00' 09.76725" N	104º 02' 51.19590" W	1414523.59	3301688.85	1414520.76	3301682.25	2.8	6.6

Table 2.1: International and Survey Foot Differences

Existing projects and extensions of existing projects should use existing project units as much as feasible. Surveyors working for MDT may encounter previous projects that used metric units on department projects in the 1990s and early 2000s. If the project involves a continuation of an existing metric design, a surveyor generally should use the existing units—with some exceptions. For example, for a new design, when doing a control densification from an existing project that was completed in metric, it may make sense to modernize a project from metric to imperial. Project units and changes to project units can be addressed through the project managers and Photogrammetry and Survey Section. Project scoping or planning, the project survey kickoff meeting, and the project control plan all present opportunities to confirm project units.

USER TIP:* *Unsure which datum an existing project used? Usually, this information can be found in the previous project's read-me file or control diagram. Previous read-me files usually contain the letters SURME in the file name. Control diagram file names usually contain the letters SUCON.

2.3 Horizontal Datums

The current horizontal datum for new projects is the North American Datum of 1983, 2011 Realization, often expressed as NAD83(2011) or NAD83-2011. Existing projects should use the same datum and realization selected in earlier parts of the project. Some datums may be on a different realization of the NAD83 datum. Previous realizations include NAD83(2007), NAD83(CORS96), NAD83(99), NAD83(92), and NAD83(86). Differences among these datum realizations, when expressed in Cartesian coordinates, like Montana State Plane Coordinate System, are generally within tenths of a foot. The NGS provides tools to convert between realizations, but conversions are not a block shift or direct computation because they are dependent on time and the speed of tectonic plates.

NAD83 is a geodetic datum. Geodetic datums have coordinates expressed as latitude and longitude. Latitudes and longitudes describe a given point's location on a mathematical ball-like sphere called an ellipsoid. The ellipsoid used for all NAD83 realizations is called the Geodetic Reference System of 1980 (GRS80). Geodetic datums are useful for geographical positioning systems GPS and geographic information systems (GIS) to use a common framework over large areas. Geodetic datums are not ideal for designing linear features like highways because something as simple as determining or designing an angle and distance between two points would require complex computations. A distance between two points easily can be computed when geodetic coordinates are projected into a Cartesian coordinate system.

USER TIP:* *You may come across another geodetic datum named WGS84. WGS84 is not the same as NAD83, but sometimes the terminology is used inconsistently and interchangeably. MDT currently uses NAD83, which is tied to State Plane Coordinate System of 1983.

Cartesian coordinate systems can be understood as an X-Y grid and have coordinates expressed as northings and eastings. MDT uses the Montana State Plane Coordinate System (MTSPCS83) for all new projects. This coordinate system has a single zone (named Zone 2500) that covers the entire state. It relies on a Lambert Conformal Map projection that is well suited for the state's east-west orientation. MTSPCS83 was created and released for use with NAD83.

2.3.1 State Plane Coordinate System Distances

Drawbacks exist, however, to using a convenient single large area system like MTSPCS83. Mapping or grid distances do not equal true ground distances. In most parts of Montana, grid distances are shorter than true ground distances (Figure 2-1). To convert back and forth between grid and ground distances, a combined scale factor (CSF) must be applied. A CSF combines a grid factor with an elevation factor by multiplying the two. Sample scale factors can be seen in Table 2.2. To determine ground distances, grid distances are divided by the CSF. Areas are converted by using a square of the CSF (ground area = grid area /CSF^2). Volumes similarly are converted by using the cube of the CSF. See Chapter 4: Control Surveys for computing scale factors on new projects.

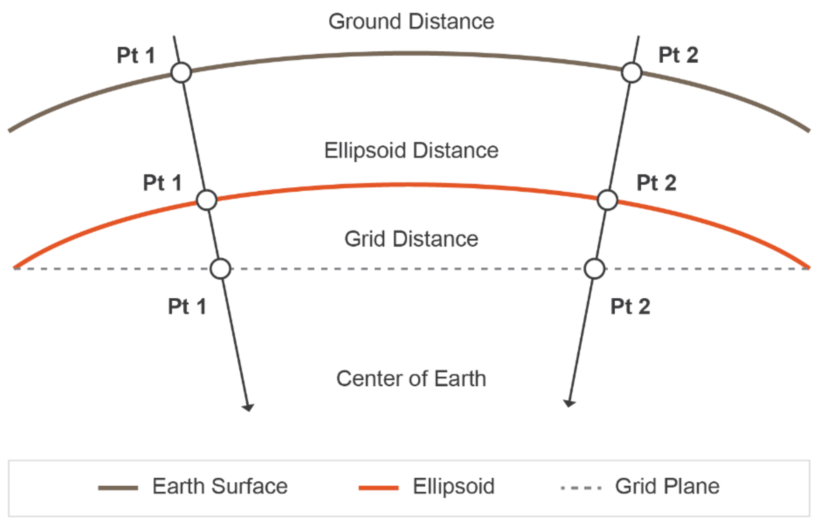

Figure 2-1: Ground distance, ellipsoid distance, and grid distance

Table 2.2 illustrates the difference between grid and ground distance over 100 feet at a given bench mark. Given structures can be hundreds or even thousands of feet in length and may use prefabricated components, the failure to account for grid-to-ground conversions in design or construction can result in unexpected errors multiple tenths in length. Procedures to avoid errors can be found in the existing bridge manual and Chapter 8: Construction Staking.

LOCATION	NGS BM	NAVD88 ELEVATION (ft)	ELEVATION FACTOR	GRID FACTOR	COMBINED SCALE FACTOR (CSF)	Δ FT (ground dist. – grid dist. in 100 ft.)
NEAR MISSOULA	SHEEP	7649	0.99963689	0.99939328	0.99903039	0.10
NEAR BOZEMAN	MOUNT ELLIS	8336	0.99960342	0.99970251	0.99930605	0.07
NEAR BILLINGS	SALZY	3960	0.99981291	0.99963857	0.99945155	0.05
NEAR SIDNEY	MONDAK	1908	0.99991166	0.99954234	0.99945404	0.05

Table 2.2: Grid and Ground Distance Comparison

2.3.2 State Plane Coordinate System Bearings

Mapping or grid north diverges from true or geodetic north as distance increases as someone moves away from the projection’s central meridian. The difference between grid north and true north is known as the convergence angle. See sample convergence angles in Table 2.3.

LOCATION	NGS BM	CONVERGENCE ANGLE
NEAR MISSOULA	SHEEP	-3º 09’ 02.1”
NEAR BOZEMAN	MOUNT ELLIS	-1 º 03’ 54.0”
NEAR BILLINGS	SALZY	+0º 48’ 15.9”
NEAR SIDNEY	MONDAK	+3º 59’ 18.6”

Table 2.3: Convergence Angles

2.3.3 Grid Stations and Offsets

While surveyors always should verify on an application-by-application basis, software using State Plane Coordinate System generally treats stationing and offsets in MTSPCS83 projects as grid distance. For example, the true ground distance at centerline from station 0+00 to 1+00 at NGS BM SHEEP in Table 2.3 would be 100.10-ft. A 50-ft. offset at the same location would be 50.05-ft. in ground distance. See Figure 2-2 below.

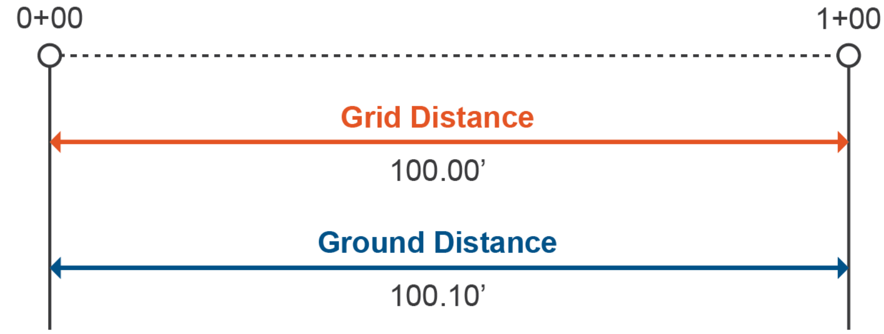

Figure 2-2: Stationing and distances

MDT began adopting State Plane Coordinate System for projects in the 1990s. MDT MTSPCS83 projects typically have notes on plan sets and project documentation describing the version of State Plane Coordinate System and project CSFs. Prior to State Plane Coordinate System adoption, MDT established bearings on a project-by-project basis with stationing and offsets representing ground dimensions.

2.3.4 Changes Ahead

Surveyors beginning a project near the release of NATRF2002 should confirm proper datum in consultation with project managers and Photogrammetry and Survey Section.

Like the U.S. survey foot, the NAD83 datum is being retired. NAD83 will be replaced by the North American Terrestrial Reference Frame of 2022 (NATRF2022). When the NGS officially releases the new datum, MDT expects to initiate all new projects on the NATRF2022 datum. When the NATRF2022 datum is released and adopted by MDT, the department also will adopt the new State Plane Coordinate System of 2022 (SPCS2022). The new map projection released for Montana for SPCS2022 appears to again call for a single zone. Linear distortion (grid vs. ground) will be improved in the SPCS2022, but it still will be significant enough to apply a CSF for the purposes of platting or construction. For surveyors beginning a project near the release of NATRF2022, confirm the proper datum in consultation with project managers and Photogrammetry and Survey Section during project kickoff meetings and control planning.

2.4 Vertical Datums

The current standard vertical datum is the NAVD88. Earlier and nonstandard projects may have relied on local datums or the National Geodetic Vertical Datum of 1929 (NGVD29).

Concurrent with ongoing geospatial changes previously discussed, NAVD88 will be retired and replaced by the North American-Pacific Geopotential Datum of 2022 (NAPGD2022). NAPGD2022 will represent a departure from a vertical datum defined by passive monuments that deteriorate with time to a vertical datum defined by measurements of gravity combined with high-accuracy GPS monitoring.

2.4.1 Geoid Models

Geoid models allow surveyors to produce orthometric heights (elevations) from the ellipsoidal heights that can be measured easily in a geodetic datum using tools like GPS receivers equipped with geospatial software. Geoid models roughly model mean sea level as shown in Figure 2-3.

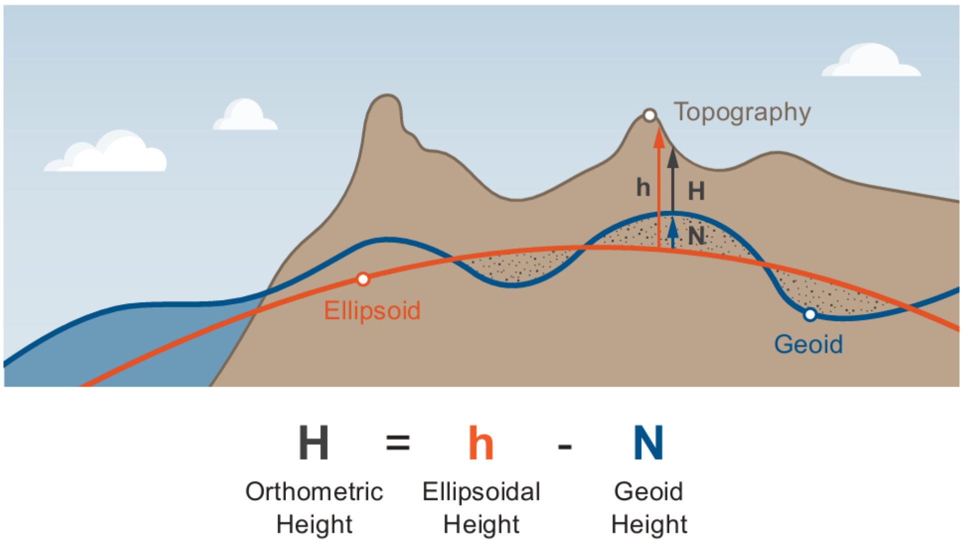

Figure 2-3: Geoid model

The current standard geoid model for new projects is GEOID18. GEOID18 is meant to be used when working with the NAD83(2011) datum. Geoid models should be used with their intended datum pair, both of which should be documented in project read-me files and the control diagram. Table 2.4 shows the proper datum pairing for recent geoid models.

The last row of Table 2.4 shows the new GEOID2022 that will be paired with NATRF2022 to get elevations on the NAPGD2022 vertical datum.

DATUM AND REALIZATION	RECOMMENDED GEOID MODEL
NAD83(1992)	GEOID09
NAD83(CORS1996)	GEOID09
NAD83(1999)	GEOID09
NAD83(2007)	GEOID09
NAD83(2011)	GEOID12B or GEOID18
NATRF(2022)	GEOID2022

Table 2.4: Datum Pairings

2.5 NSRS Modernization

The NGS is in the process of modernizing the National Spatial Reference System (NSRS). NSRS modernization includes:

- Retirement of the U.S. survey foot, making the international foot the uniform unit of measurement in the United States. This change occurred at the end of 2022.
- Release of new horizontal datum terrestrial reference frame NATRF(2022).
- Release of new coordinate systems with SPCS2022.
- Release of new vertical datum NAPGD2022 and associated GEOID2022 geoid model.

Unlike the deprecation of the U.S. survey foot, the schedule for completing the other portions of the NSRS modernization program are currently unclear, and it could be multiple years before the program is fully realized.

Updates to this section are anticipated in the future as portions of the modernization program have been delayed until 2024-2025 or later.

2.6 Real Time Networks (RTNs)

RTNs are a geospatial technology trend that has not fully arrived in Montana, but beta testing is ongoing, and RTNs likely will be a part of our collective surveying future. RTNs use a network of stationary GPS receivers to provide a real-time correction to rovers via cellular data, allowing for surveys to be completed without the base part of a base/rover pairing.

Successful application of RTNs will require users to have a complete understanding of the type of coordinates being broadcasted and how their field software translates this into the project coordinates of the future.

CHAPTER 3

EQUIPMENT

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CHAPTER 3 | EQUIPMENT

3.1 Introduction

Surveyors have different tools for different tasks, and selecting the proper tools is a key part of planning a survey project. Each tool has its strengths and limitations. Surveyors completing Montana Department of Transportation (MDT) projects use total stations, global navigation satellite system (GNSS) receivers, and digital levels for most projects. These tools are then supplemented with specialized tools to meet a given project's needs, such as terrestrial or mobile lidar scanners, echosounders, and unmanned aerial vehicles (UAVs, also known as drones). Ultimately, the responsible surveyor in charge of a project determines which tools to use. Other specialized equipment not listed or newly emergent can be considered and discussed during project planning and scoping. The complete survey requirements, equipment, and approach can be confirmed during the survey scoping meeting. Deliverables and submittal standards related to equipment are discussed in the appropriate chapter(s).

3.2 Peripheral Equipment

Adjusted rods and tribrachs allow more complicated pieces of equipment to reach their accuracy potential. Rods have a circular bullseye bubble that needs to be checked and adjusted regularly. Survey rods are used daily and need to be checked and regularly adjusted for plumbness. Tribrachs have an optical or laser plummet to position the tribrach over a point. Adjustments to a tribrach should either be left to trained adjustment professionals or performed in accordance with the manufacturer's recommendations.

USER TIP:
Keeping your peripheral equipment adjusted allows the rest of your equipment to reach its full accuracy potential.

3.3 General Equipment Maintenance and Care

Equipment maintenance, general care, and calibrations should be completed according to the equipment manufacturer's recommendations and industry standards of practice.

Baseline calibration reports are expected to be completed yearly and in advance of each project for total stations and GNSS receivers. The reports indicate the difference between measured and recorded distances at calibrated baselines. The difference between measured and expected distances should be analyzed, and equipment with greater differences than expected should not be used on project surveys until the equipment has been serviced and proven to be operating correctly.

Calibration reports should be submitted for equipment used in control, cadastral, and/or engineering surveys.

Equipment should be transported in its assigned case. No survey equipment should be transported in the back of a truck unless there is a containment system for the equipment. GNSS receivers should be removed from their tribrach or survey rod prior to transport.

3.4 Total Stations

USER TIP:
Using an active target with a robotic total station can prevent collection of points on unintended targets.

Modern total stations measure horizontal and vertical angles and combine this information with distances on an onboard electronic distance meter (EDM). Measurements are made from the instrument (the total station itself) to a rod, which is typically a target mounted to a tripod or survey pole. Some surveyors use mechanical total stations operated with a surveyor at the instrument, but many surveyors use robotic total stations that allow a surveyor to operate the instrument remotely (e.g., from the rod). Total stations vary in their angular accuracy and thus in their suitability for collecting or laying out data. A well-adjusted modern total station with consistent practices currently outperforms GNSS in terms of relative horizontal and vertical positioning over short distances, making total stations the preferred tool for construction staking and mapping elevation-critical data like curb lines and manhole rims.

Avoiding common errors will help improve the quality of the final survey product. Some common errors to avoid include:

- Measure-up errors at instrument and rod.
- Wrong prism constant.
- Wrong temperature and atmospheric pressure.

  Note: If a total station does not have an internal barometer, the atmospheric pressure entered typically is required to be in absolute pressure rather than barometric pressure from the local weather report, which is typically expressed relative to sea level. Absolute pressure may be obtained from a nearby weather station like an airport or from a barometer calibrated to absolute pressure at a nearby weather station.
- Curvature and refraction not turned on in data collection or processing software.
- Failure to perform routine user instrument calibrations.
- Instrument and rods out of plumb.
- Error in backsight angle.
- The angular amplification of error.
- Robotic instruments locking onto unintended targets.

3.5 GNSS Receivers

The GNSS comprises the GPS constellation operated by the United States, together with additional constellations including BEIDOU (operated by China), GALILEO (European Union), and GLONASS (Russian Federation).

The GNSS is a system of multiple satellite constellations that includes the Global Positioning System (GPS) constellation operated by the United States. GNSS receivers determine positions by counting wavelengths from various satellites in the GNSS network. The GNSS network comprises GPS (constellations maintained by the United States) plus constellations such as BEIDOU (China), GALILEO (European Union), GLONASS (Russian Federation), and other satellite constellations.

Common errors to avoid in operating GNSS receivers include:

- Measure-up errors at base or rover.

  MDT prefers fixed-height systems whenever available.

- Multipath interference.

  Multipath interference is the phenomenon of GNSS signal waves bouncing off trees, urban canyons, walls, tall fences, and any other object separating the GNSS receiver from satellites. See Figure 3-1 for examples. In high-multipath environments, GNSS signals bounce off obstructions and take multiple paths to the receiver, causing errors in counting the number of wavelengths and resulting in positional errors varying from tenths of a foot to multiple feet.

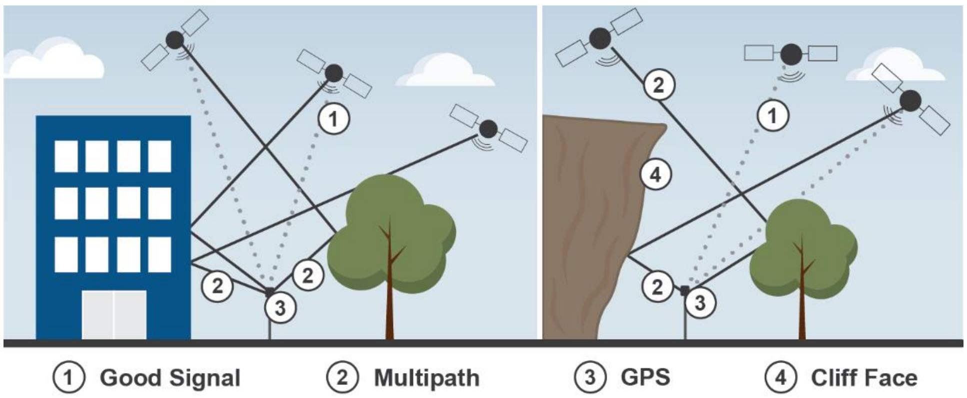

Figure 3-1: Examples of high-multipath environments

- Errors in the application of software related to geodetic computations, including coordinate systems, map projections, and GEOID models.

- Poor satellite geometry.

3.5.1 GNSS Corrections

Correction techniques enhance the quality and improve the accuracy of data collected using GNSS receivers. A variety of ways of correcting GNSS data have been developed.

3.5.1.1 Base or Multiple Bases on Known Coordinates

Real time kinematic (RTK) positioning includes a correction with a radio or data modem, which typically has indicators of data quality.

Post-process kinematic (PPK) positioning is less commonly used and is more limited for indications of data quality at the time of survey.

3.5.1.2 Real Time Networks (RTN)

RTNs may be considered for cadastral and control surveys in the future. See Chapter 4: Control Surveys. RTN corrections are delivered via a data modem. Potential use of the RTN for project activities should be discussed during the survey scoping meeting.

3.5.1.3 Processing Options and Services

Use of third-party processing services other than OPUS Projects and OPUS should be discussed during the survey scoping meeting.

3.6 Differential Levels

MDT survey projects use differential levels to determine accurate elevations. Most levels used on MDT survey projects are digital levels that read a bar code.

Common errors to avoid include:

- Collimation errors – level not reading true straight line.
- Curvature and refraction.
- Misreading of rod through optical level.
- Rod not plumb.

Differential levels should be peg-tested before beginning a project and daily while in use.

3.7 Laser Scanners

Scanning can be beneficial when a project requires a high level of detail in existing conditions or when an area is difficult or dangerous to survey directly with GNSS or a total station. Scanners emit laser pulses to measure the distance between the scanner and environmental features.

The process of orienting and aligning multiple scans is referred to as registration. The complexity of registration depends on the scanning technology and software deployed for the project. The process of determining coordinate values (northings and eastings) and elevations of scan datasets is referred to as georeferencing. All scan data for MDT should be registered and georeferenced to project control. See Chapter 7: Remote Sensing for standards for laser scanning.

Scanning total stations and terrestrial laser scanners are placed on a tripod or other fixed surface.

Georeferencing – In the context of scanning, georeferencing refers to the process of determining coordinate values and elevations for the scanned dataset.

Mobile laser scanning systems, also called mobile lidar, are mounted to a vehicle and collect scan data as the vehicle moves through its environment.

3.7.1 Terrestrial Scanners

Terrestrial scanners include scanning total stations and static scanners.

3.7.1.1 Scanning Total Stations

Scanning total stations combine a total station with a laser scanner. These instruments benefit from having a similar workflow to total stations with the instrument being oriented by an observation from a control point to one or more control point backsights.

Scanning total stations excel at targeted scans of select locations because they can be constrained to a limited field of vision. They also can perform full-dome scans of the entire field of vision but may be slower at this task than terrestrial scanners. These instruments are more readily available to MDT survey crews as they can be used to perform traditional total station tasks like construction staking and mapping.

3.7.1.2 Static Scanners

Unlike scanning total stations, dedicated terrestrial scanners may require survey control values to be determined at three or more target locations.

Because they collect higher volumes of data than current scanning total stations, terrestrial scanners excel in areas that benefit from repeated scans of the entire field of vision, also known as full-dome scans.

3.7.1.3 Terrestrial Scanning Common Errors

Common errors include:

- Point cloud not level or tilted.
- Point cloud mismatched from itself and other topography.
- Errors at long distances.
- Poor results in areas of low reflectivity.
- Poor results in areas with high reflectivity (e.g., mirrors, shiny objects, washed and polished cars).
- False returns and extra noise in the data created by humidity (e.g., scanning in the rain).
- Systemic errors in sensors.

3.7.2 Vehicular Mobile Lidar

Mobile lidar combines a lidar sensor with other sensors such as an inertial measurement unit (IMU).

Mobile lidar excels at rapidly gathering large mapping datasets of corridor data. Relative to terrestrial scanning, mobile lidar requires more sophisticated processing and experienced operators.

Common errors generally include the same errors listed above for terrestrial scanning in addition to more systemic and operational errors from additional sensors and complexity.

3.8 Other Equipment

3.8.1 Data Collectors

Data collectors serve as the interface between the user and survey instrumentation like total stations and GNSS receivers in the field. A data collector is essentially a small computer running surveying software. Data collectors require a means of communication to survey instrumentation. Connection to instrumentation may be accomplished via cable, radio, WiFi, or Bluetooth (a short-range, low-power radio).

Data collectors need to be configured with the proper coordinate system, geoid model, and feature code library (see Chapter 5: Engineering Surveys).

3.8.2 Unmanned Aerial Vehicles

Proposed use of UAVs should be discussed during scoping and at the survey scoping meeting. MDT evaluates their appropriateness on a project-by-project basis. See Chapter 7: Remote Sensing.

3.8.3 Echosounders

Proposed use of echosounders should be discussed during scoping and at the survey scoping meeting. Surveyors use bathymetric echosounders to determine the depths of water body floors. Single-beam echosounders collect data at a single point by determining the depth from the echosounder transducer to the water floor. This method is commonly used for simple river cross sections that are too deep to wade. Multi-beam or side-scan echosounders are more complex and can produce a detailed point cloud.

CHAPTER 4

CONTROL SURVEYS

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4.1 Introduction

Control surveys establish a permanent, recoverable, and repeatable horizontal and vertical control network upon which subsequent project surveys are based. Control surveys may rely on existing control from a previous project, or they may be new survey control networks on the department's current standard horizontal and vertical datums (see Chapter 2: Coordinate Systems and Datums). Previous project control may be considered when an adjacent project has data that can be used for the current project's design needs or if the current project is an extension of a previous project's design. New control network values may be determined from static network surveys constrained to physical control marks and/or Continuously Operating Reference Stations (CORS). Terrestrial total station observations can be used in combination with GNSS survey methods and should be used when establishing control in high-multipath environments. Previous project control and new control options should be discussed and confirmed during the survey scoping meeting.

4.2 Survey Scoping Meeting

A survey scoping meeting is recommended prior to developing a control plan to discuss specific survey needs for the project including density and location of control points. To prepare for the meeting, the survey team should communicate with project designers to understand the design objectives of the project, including anticipated future construction limits and estimated construction timelines.

The scoping meeting should also address these questions:

- Approximately where is control expected to be needed? The project preliminary field report (PFR) provides basic information on the planned horizontal alignment, vertical alignment, and typical sections.
- Is there suitable existing MDT control already in place or near the project location?
- What methods will be used for horizontal control?
  - GNSS observations, total stations observations, or both?
  - Will the project use a survey control network, the Montana State Reference Network (MTSRN), or be treated as secondary control?
- What primary control points (e.g., CORS stations) are available for the project, and how far are they from the site?
- Will the project use differential levels or GNSS observations for vertical control?

- Urban projects and projects featuring bridges or similar substantial structures should use differential levels for vertical control of project, aerial, and secondary control. Rural projects may use GNSS observations and the appropriate geoid model to establish elevations.
- Both rural and urban projects that involve aerial mapping typically require differential levels. These requirements should be discussed during the survey scoping meeting.

4.3 Control Plan

The survey control plan is submitted after the survey scoping meeting. The plan should identify the following:

- Proposed horizontal and vertical datums.
- Proposed existing or primary control stations.
- Proposed monumentation and locations.
- Proposed horizontal and vertical control methods.
- Proposed planned equipment, including GNSS receiver type and quantity, total station(s), and differentials level(s).

For consultant projects, the control plan is submitted through the consultant design project manager, or the term contract point of contact. The control plan should be reviewed and approved by the land survey manager or designee prior to conducting control activities.

4.4 Point Naming

Projects using existing control should continue to use the existing point designations established by the initial control survey. Do not restamp or rename existing control marks. NGS control marks or CORS stations should be named the station name. Avoid duplicating point names.

4.4.1 New Project Control

New project control should be named consecutively with alpha characters and a suffix of the project UPN. The first three project control points for a project with a UPN of 7342 would be named A7342, B7342, and C7342. Avoid using alpha characters I, O, and Q to avoid confusing the characters with similarly shaped numbers. If additional points are needed after Z7342, the first three additional new points would be named AA7342, AB7342, and AC7342.

4.4.1.1 Projects without a UPN

There is no standard for control point naming on projects without a UPN. A point naming scheme for these types of projects can be coordinated with the land survey manager and the appropriate MDT district land surveyor. Project control for projects without a UPN are otherwise not treated differently from normal project control points.

4.4.2 New Aerial Control

Aerial control points should be numbered consecutively beginning at 600 with a four-digit suffix of the project UPN. The first three aerial control points for a project with a UPN of 7342 would be 6007342, 6017342, and 6027342.

4.4.3 Secondary Control

If features requiring survey cannot be surveyed using original project control and/or aerial control, secondary control may be set as needed. Secondary control points should be numbered with any regular numeric value of 50,000 and above. Survey should confirm point availability with the project manager prior to naming new secondary control points as this point range is also used in other survey phases.

4.4.4 Reset Control

If an existing control mark is in danger of being destroyed or disturbed by construction, it may be referenced and then reset. The new point should be named with the original name and a suffix of "RESET" and the date of the year it was reset.

If the mark being reset is an NGS bench mark, additional information on resetting can be found in the NGS Bench Mark Reset Procedures. Only 1st and 2nd Order vertical marks should be reset; 3rd Order marks should not be reset. Marks that have already been reset should not be reset a second time.

4.5 Control Monumentation

4.5.1 New Project Control

Standard monumentation for project control is a 5/8-in. x 30-in. rebar with 2-in. aluminum cap for soft surfaces. Caps should be marked with the point name and punch at a minimum. Standard monumentation also may include a brass plug or similar metal monument, countersunk slightly below grade, as to avoid being struck by snow removal equipment. Use ferrous materials or include magnets when installing hard surface control points.

USER TIP:
Control points set below grade may need to have extra surface material removed to accommodate the bottom of a level rod during differential leveling.

For long-term projects or projects with limited NGS bench marks available, MDT prefers two or more stainless-steel rods driven to refusal. Stainless-steel rods should be encased in a monument box with the point name marked on the monument box. Detailed schematics of rod installation can be found in the NGS Bench Mark Reset Procedures.

A carsonite, aluminum, or similar semi-permanent witness post should be set near the monument when practical.

4.5.2 Aerial Control

Like project control, the standard monumentation for aerial control is a 5/8-in. x 30-in. rebar with 2-in. aluminum cap at the target center or other target pick point identified by the aerial mapping provider. Hard surfaces are typically painted on asphalt or concrete and monumented with a survey nail or similar marker at the target center or an alternate target pick point designated by the aerial mapping provider.

4.5.3 Secondary Control

A hub and tack, survey nail, or similar marker is acceptable secondary control monumentation if the control point is for a single use. Secondary control points that will be reused should be monumented consistently with the standards for new project control above.

4.6 Control Point Spacing and Locations

Project control points should be placed in locations that are:

- Safe and easy to access.
- Practical for data collection and future staking purposes.
- Outside of project construction limits.
- Within the project right-of-way.
- Intervisible with two or more points when feasible.

USER TIP:* *Often a project control point and/or aerial mapping control point can serve double duty to satisfy both control point spacing requirements and aerial control requirements.

Points should be set at a maximum spacing of 1,000-ft. or less and an average spacing of 750-ft. or less. Bridges require at least four control points with two azimuth pairs at each end. Points that are planned to be surveyed with GNSS observations should be placed in low-multipath environments. All control points should be intervisible with two or more other control points.

High-elevation control locations are desirable when feasible, particularly in rugged terrain, to maximize potential radio transmissions. Control locations on roads away from anticipated construction are also desirable to preserve control for the life of a project.

The ideal control scheme has control points placed along both sides of the present traveled way, alternating from side to side, but a single side of the present traveled way may be used to accommodate terrain or conditions (e.g., limited sight distances, excessive vegetation, or natural obstacles such as steep terrain or rivers).

Avoid placing control:

- On steep slopes where it will be difficult to set up a tripod.
- In farmed ground.
- On the approaches of reconstruction projects.
- Above underground utilities.
- Above or near existing culverts.

Aerial control points should be located consistently with guidance from the project aerial mapping provider. The direction and distance these points can be moved from their planned locations are a function of the aerial mapping flight plan, but they generally can be moved up to 100-ft. from the planned location without issue. New primary control and aerial control points near each other (i.e., < 150-ft. spacing) are not required or desired by MDT. For example, a planned aerial control point and new primary control point on opposite sides of a street typically can be consolidated into a single control point. See Chapter 7: Remote Sensing for additional information on aerial mapping targeting.

Passive NGS control marks within the project limits should be included in the project control survey. See Figure 4-1 for an example of typical project control locations.

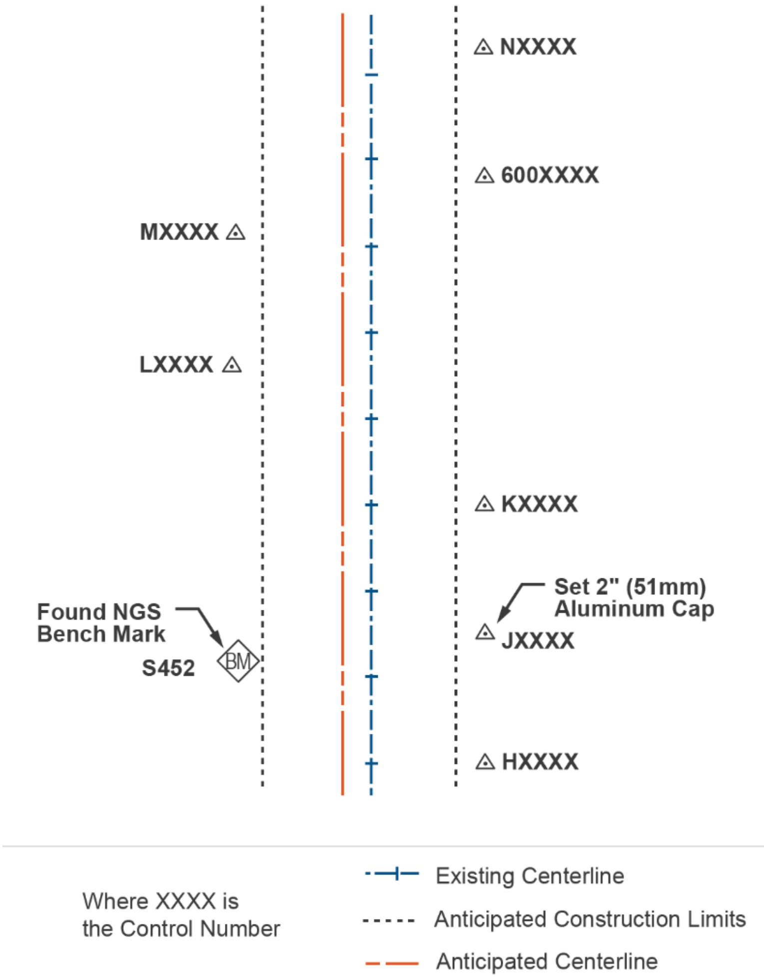

Figure 4-1: Typical GPS project control mark locations

4.7 Log Sheets

MDT uses and requires observation log sheets for some control activities.

Total station observation logs should document point names, instrument heights, target heights, and target prism constants.

GNSS observation logs should document receiver type, receiver serial number, start time, end time, and antennae heights and the points at which they are measured.

4.8 Field Practices

MDT prefers fixed height tripods when they are available for control surveys. If standard adjustable height tripods are used at a given point for multiple observations, MDT requires a difference of 0.33-ft. or greater between the measured height of the receiver for the observations.

Heights should be measured in metric and English units, with the metric measured value converted into English units and compared to the measured English units.

Equipment and procedures should be used that result in expected centering and measure-up errors of less than 0.01-ft.

Document the location of control points relative to other local features. Each project and aerial control point requires a description in the project's control abstract. See Figure 4-2 for examples.

CONTROL NUMBER: 9999
PROJECT ID: NH 9-99(99)999
LOCATION: SOMEWHERE IN MONTANA-EAST AND WEST

MARK	DESCRIPTION
A5559	SET MDT ALUMINUM CONTROL CAP STAMPED "A5559 2005" ON A 5/8" REBAR, AT RP 399.123, 65' SOUTH OF PTW OF HIGHWAY 2, 5' SOUTH OF A FENCE, AND 5' SOUTH OF A WITNESS POST.
B5559	SET MDT ALUMINUM CONTROL CAP STAMPED "B5559 2005" ON A 5/8" REBAR, AT RP 399.450, 80' NORTH OF PTW OF HIGHWAY 2, 120' EAST OF A FARM ROAD, 3' NORTHWESTERLY OF A POWER POLE, AND 5' SOUTH OF A WITNESS POST.
T335	FOUND NGS BENCH MARK IN A CONCRETE POST STAMPED "T335 1938", AT RP 399.853, 55' NORTH OF PTW OF HIGHWAY 2, 5' NORTH OF A FENCE, AND 3' WEST OF A NGS WITNESS POST, SEE NGS DATA SHEET FOR ADDITIONAL INFORMATION.
C5559	SET MDT ALUMINUM CONTROL CAP STAMPED "C5559 2005" ON A 5/8" REBAR, AT RP 400.144, 80' SOUTH OF PTW OF HIGHWAY 2, 2'NORTH OF A FENCE, AND 5' SOUTH OF A WITNESS POST.
400A	FOUND MDT ALUMINUM CONTROL CAP STAMPED "400A 1997", AT RP 400.329, SET IN CONJUNCTION WITH CN 2235, 82' NORTH OF PTW OF HIGHWAY 2, 3' WEST OF POWER POLE, AND 2' NORTH OF A FENCE, AND SET NEW WITNESS POST 3' SOUTH.
603	FOUND MDT ALUMINUM CONTROL CAP STAMPED "603 1997", AT RP 400.674, SET IN CONJUNCTION WITH CN 2235, 50' NORTH OF THE PTW OF HIGHWAY 2. 3' NORTH OF A FENCE. AND SET A NEW WITNESS POST 3' NORTH.

Figure 4-2: Sample control abstract

4.9 Horizontal Control

Project and aerial control horizontal values may be established via a new control network, MTSRN observations, or as secondary control. The anticipated method of horizontal control should be confirmed in the survey scoping meeting.

4.9.1 New Control Network

A new control network may need to be established for projects in areas without existing usable control nearby. Determination of new network control values is determined using a combination of GNSS fast-static observations, total station observations, and differential leveling.

4.9.1.1 Primary Control Sources

All primary control sources need to be on the designated project horizontal and vertical datums. At least three primary control sources are required for new network control surveys. Depending on the project location and control availability, MDT accepts the following types of primary control sources:

- CORS stations.
- NGS control marks with horizontal and vertical values published for the project datums.
- A substantial monument (e.g., a stainless-steel rod driven to refusal) with a mean of two or more Online Positioning User Service (OPUS) solutions.
- A mean of OPUS solutions from GNSS observations for new primary control, meeting the following standards:
    - Each observation four hours or longer in duration.
    - The differences in the grid coordinates from the two solutions should be less than 0.05-ft. in northing and easting, and less than 0.07-ft. in elevation.
    - > 50% ambiguities should be fixed.
    - > 90% observations should be used.
    - Overall RMS < 0.10-ft.
    - Peak-to-peak errors < 0.16-ft.
- Existing MDT survey control points, preferably in the form of substantial long-term monuments such as stainless-steel rods or dig-in type flared-end monuments.
- If existing MDT survey control is planned to be used, MDT typically will provide:
    - Existing control data coordinate files, typically provided as an ASCII file with an .ift extension.
    - An existing control read-me file describing project datum, coordinate system, units, and control methodology, typically provided as an ASCII file with an .rme extension.

USER TIP:
When possible, avoid mixing passive NGS marks with CORS stations for a primary control plan as doing so can potentially cause networks to fail.

4.9.1.2 Primary Control Locations

Primary control sources should be located in three or more quadrants relative to the project location. Figure 4-3 shows primary control points F204, H570, and TAYLOR in three separate quadrants relative to the project limits.

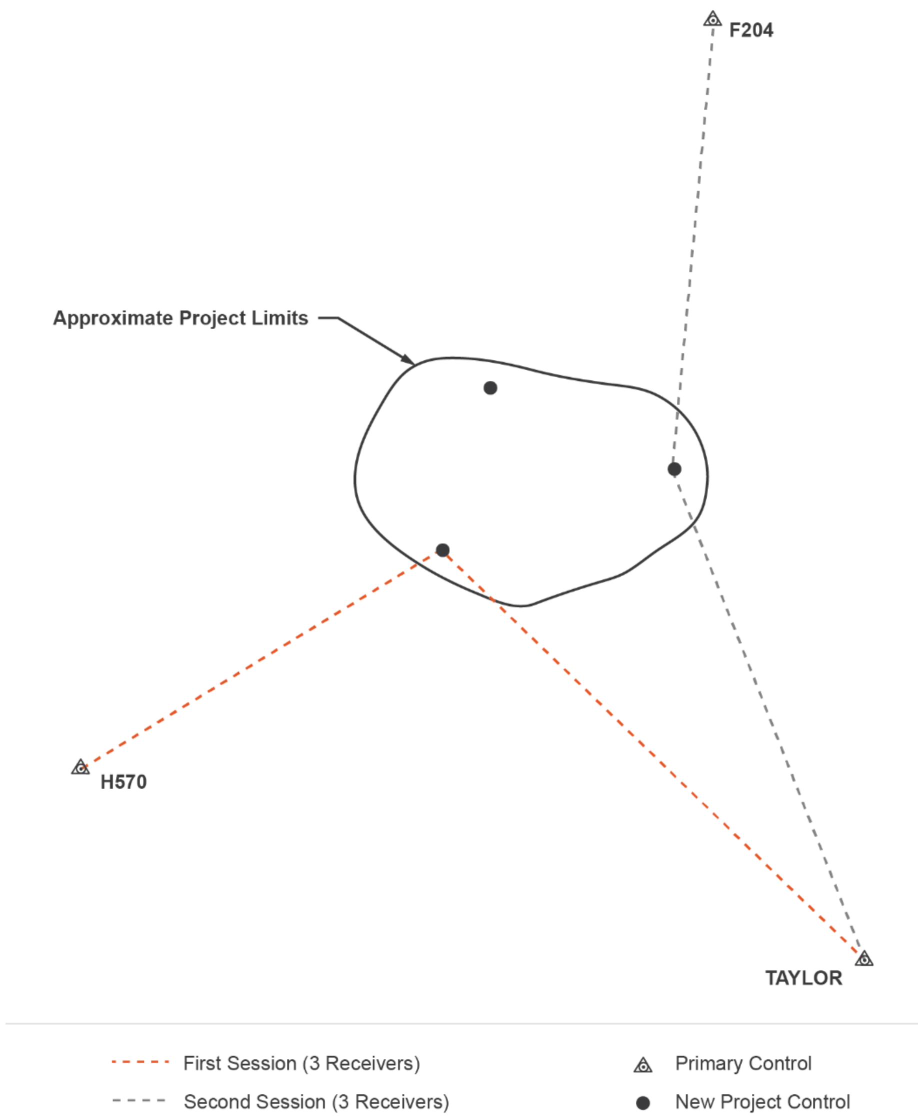

Figure 4-3: Project control quadrants

4.9.1.3 Network Planning

The goal of the survey network is to tie all required project and aerial control to each other and the primary control source. Each network is unique but should generally adhere to this guidance:

- All points should be connected to at least two other points with an independent enabled GNSS baseline or total station observation.
- Each point connected to the network exclusively by GNSS observations should be observed at least twice in separately enabled observations.
- All final GNSS baselines used must be independent. Independent baselines also may be referred to as nontrivial. The formula for determining how many vectors can be used for a session is n-1, in which n is the number of receivers being used for the session.

- Total station networks may benefit from cross-ties.
- Plan for enough observations to exceed 25 percent or more redundancy in enabled final observations. Redundancy can be computed by the following equation: (repeated observations in final network) / (total number of observations in final network).
    - To qualify as a redundant GNSS observation, both stations at each end of the baseline should be reset and reobserved.
    - Observations from CORS stations or similar fixed reference stations that cannot be reset between sessions are considered redundant if the roving segment of the survey is reset.
- Points in low-multipath areas should be surveyed by GNSS.
- Points in high-multipath areas should be surveyed by total station.
- Projects for which GNSS observations are impractical for the entirety of the project can be discussed on a case-by-case basis in the survey scoping meeting. Most project environments allow for at least one azimuth pair or, preferably, an azimuth pair at each end of the project.
- See Figure 4-4,Figure 4-5, and Figure 4-6 for sample control configurations.

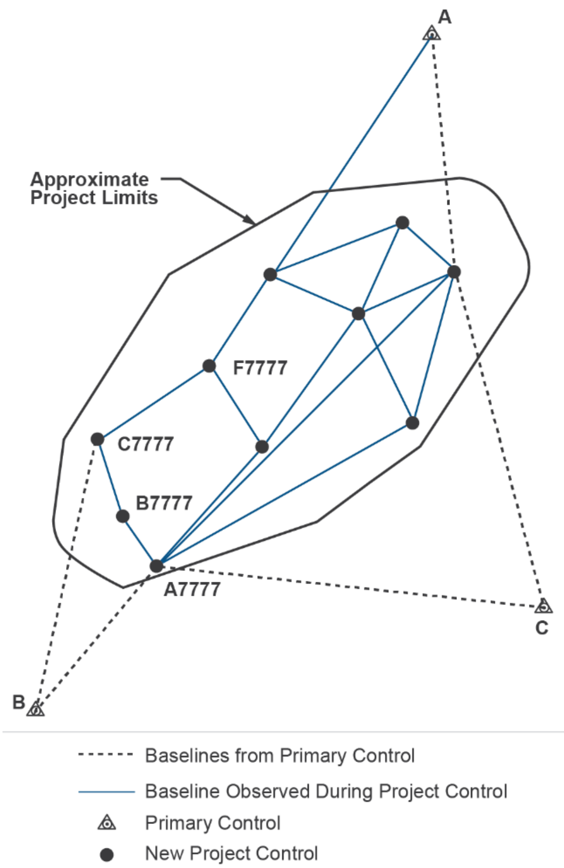

Figure 4-4: Network configuration loop

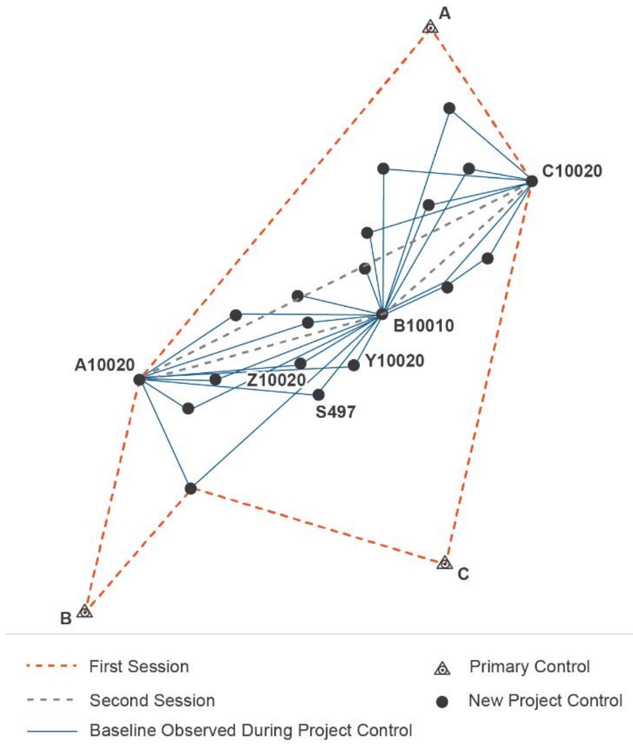

Figure 4-5: Network configuration radial

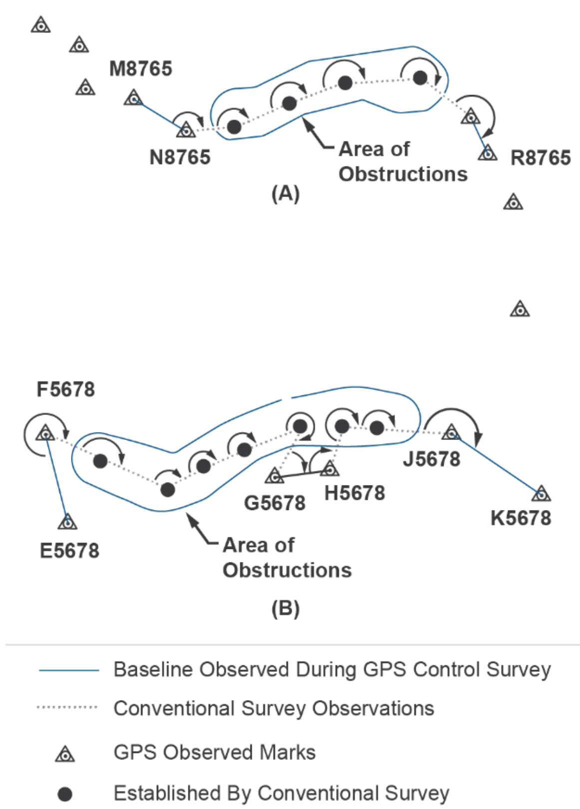

Figure 4-6: GNSS obstruction and conventional survey control

4.9.1.4 Observation Guidelines

GNSS Observation Guidelines:

- 15-minute minimum observation time.
- Recommended minimum observation length of 2 minutes per kilometer of baseline length which equals roughly 1.2 minutes per mile of baseline length.
- Minimum durations reflect time of simultaneous occupation between points.

Total Station Observation Guidelines:

- Two sets of angles minimum with observations from direct and reverse face in each set.
- Maximum mean angle residuals:
    - 5 seconds in horizontal or vertical angle.
- Maximum slope distance residual: 0.02-ft.

4.9.1.5 Network Processing

GNSS Baseline Processing:

Least squares is the standard method of adjusting control networks of GNSS data, total station data, or combined GNSS and total station data. The processing steps are:

- Review antennae heights and point names during import, confirming heights in software match heights written in the field notes.
- Populate control coordinates for primary control points.
    - CORS station or NGS control mark coordinates typically entered as geodetic latitude, longitude, and ellipsoidal height in the project datum.
    - Meaned OPUS solutions, typically entered as a geodetic latitude, longitude, and ellipsoidal height in the project datum.
    - Existing control, when appropriate, typically entered as grid coordinates in the existing project coordinate system and units.
- Import the GNSS satellite ephemeris(es).
    - MDT accepts rapid or precise ephemerises.
- Set the elevation mask to 10 degrees minimum.
- Process baselines and work through them in an iterative fashion, beginning by disabling trivial vectors and unintended short-duration baselines.
- If a planned baseline is disabled, it may be useful to enable another baseline from that session that was initially planned to be treated as a trivial baseline.

- Baselines between primary control stations eventually should be disabled but may be useful to toggle on to evaluate how well control stations fit between each other.
- Evaluate all redundant vectors.
  - Differences in vector ellipsoid lengths and Δ ellipsoidal height should be $\leq$ 0.10-ft.
- Review GNSS loop misclosures. MDT accepts loop closures of < 5-cm (0.16-ft.). A well-executed network with adequate redundancy should achieve loop closures of < 2.5-cm (0.08-ft.) horizontal and < 3.5-cm (0.11-ft.) vertical.

Total Station Observation Processing:

Review observations by confirming instrument and target heights in software match heights written in the field notes. Confirm all final enabled observations meet the following total station observation criteria:

- Two sets of angles minimum with observations from direct and reverse face in each set.
- Maximum mean angle residual of 5 seconds in horizontal or vertical angle.
- Maximum slope distance residual of 0.02-ft., with any residual greater than 0.01-ft. reviewed for reasonableness.

4.9.1.6 Network Adjustment

The following guidelines apply to network adjustments:

- Set confidence intervals to 95%.
- Set default standard errors at:
  - 0.007-ft. for error in height of antenna.
  - 0.005-ft. for instrument centering error.
- Perform minimally constrained adjustment(s) to analyze how the network fits itself and other primary control sources if constrained to a single point horizontally and/or vertically.
- Disable and enable observations as needed and recheck.
- Following the minimally constrained adjustment, apply a scalar if necessary, and perform a fully constrained adjustment, holding the horizontal values of three or more primary control points and the vertical values of one or four or more primary control points. Selection of which vertical values to hold is left to the discretion of the surveyor but should be consistent with the project control plan. If more than one point is held in the vertical network, resulting network tilt should be monitored.
- The network reference factor should typically be below 2.0. If it is greater than 2.0, issues may need to be resolved before continuing with the adjustment. A network reference factor of 1.0 means the

Network adjustments are typically an iterative process that may require enabling and disabling baselines while maintaining the proper amount of nontrivial vectors.

network is behaving as expected statistically, given the observations in the network and the expected errors entered into adjustment software.

- Verify the final adjustment passes the Chi-Square test.
- Review the network adjustment report. No residual in any component in a Least Squares Adjustment should exceed 0.10-ft.

4.9.2 MTSRN Control

The MTSRN allows for real-time and post-processed positioning from a network of high-accuracy sensors throughout the state. Real-time corrections require a data connection, typically delivered via cell coverage. Coverage throughout the state is variable and currently unavailable in some locations. In addition to standard GNSS concern for multipath, MTSRN users also need to be aware of their baseline lengths, station satellite availability including constellation availability, and Virtual Reference Station (VRS) solution coverage. The MTSRN can be used to establish project control, aerial control, and secondary control by applying the following standards:

- Two observations minimum, spaced at least three hours apart. The second observation should not be on a 12-hour cycle from the first observation. For example, a point observed at 8 a.m., should not be reobserved at 8 p.m., but that observation would be acceptable if performed 3 hours before or after the 12-hour cycle at 5 p.m., or 11 p.m.
- 300 epoch minimum observation length.
- Differences in observations should be less than 0.05-ft. in horizontal distance and 0.05-ft. in vertical distance.
- Except for using MTSRN for secondary control, all control points established using the MTSRN require post-processing using a hybrid method and OPUS Projects 5.0 or comparable software.

4.9.3 Secondary Control

Secondary control may be necessary to collect topographic features or perform construction layout.

Secondary control can be added in low-multipath environments using GNSS observations from project control, aerial control, or the MTSRN if the MTSRN was used to establish the initial project control. GNSS observations should be:

- Two observations minimum from different control points with no time separation requirement between observations.
- 300 epoch minimum observation length.
- Performed from primary control stations.

Differences in observations from multiple GNSS or total station observations should be less 0.05-ft. in horizontal distance and less than 0.05-ft. in elevation. Vertical is generally not a concern if the control is being leveled, but significant vertical differences may indicate poor conditions for GNSS observations.

In locations where GNSS observations are impractical, total stations also can be used to establish secondary control values by performing a closed traverse.

Resections are acceptable for determining secondary control values if they use three or more project or aerial control points. A three-point resection should have residuals less than 0.03-ft. in any component.

4.10 Vertical Control

Differential levels are required for all urban projects and projects involving bridges or other substantial structures. Elevations for project, aerial, and secondary control points should all be determined using differential levels.

Standards for differential level runs:

- The level should be peg-tested daily.
- Maximum misclosure for differential levels can be computed by the following equation: 0.018-ft.* $\sqrt{D_m}$, in which D_m is total distance of backsights and foresights in Miles or 0.005*$\sqrt{D_K}$ in which D_K is total distance in Kilometers. For example, a differential leveling loop of 4000-ft. (4000/5280= 0.758 miles) of foresight and backsight distances would have a maximum misclosure of 0.018-ft.* $\sqrt{0.758}$ = 0.016-ft. A short differential leveling loop of 528-ft. would have a maximum misclosure of 0.018-ft. * $\sqrt{0.100}$= 0.006-ft. For an example in Kilometers, a differential leveling loop of 4000-M of foresight and backsight distance would have a maximum misclosure of 0.005*$\sqrt{4}$=0.01-M
- Final level values should be adjusted using a least squares adjustment program, and final level values should be used going forward for all leveled points in project deliverables (see below), including .ift file. If not, all points are leveled; the .ift file should distinguish those elevations established by differential levels.

Rural projects without bridges or other substantial structures may rely on a GNSS or MTSRN observations and the appropriate geoid model to determine vertical values. Differences in GNSS or MTSRN observations should be less than 0.05-ft. horizontal distance and less than 0.05-ft. in elevation.

4.11 Deliverables

The following items are required deliverables for control surveys but do not have strict file-naming conventions:

- The approved control plan, provided as word processor document or PDF.
- PDF of field notes for all survey activities, named logically at the discretion of the surveyor.
- All supporting data and calculations for control activities, which may include some or all of the following:
    - Computations showing means or weighted means.
    - Minimally constrained adjustment report.
    - Fully constrained adjustment report.
    - GNSS loop closure report.

- Observation files.
- OPUS solutions.
- NGS datasheets.
- Differential leveling least squares adjustment report.
- GNSS processing files compatible with MDT's current software.
- Data collector files.

The items listed below are also required for control surveys, but these files do follow a strict naming convention. Sample file names below are for a consultant project with a UPN of XXXXXXX. Consultant files typically have a Z0# suffix that precedes the file extension. Files generated by MDT have a numeric *0* instead of an alphabetic *Z*. ASCII files should be space delimited (NOT tab or comma delimited).

.IFT – ASCII English units coordinate file (point, northing, easting, elevation) in the proper project units. Coordinates should be provided for all project and aerial control points. Include a note of the datums, adjustment tag, and geoid model used. Vertical values in the .ift file should be final differential leveled values on projects using differential levels for vertical control. If all points for a project are not leveled, the .ift file should identify which vertical values were determined by differential leveling and which vertical values were determined by GNSS or total station observations. *Sample name: XXXXXXXSUCONZ01.IFT*

.DES – ASCII points abstract with descriptions of points in the vicinity of the project. *Sample name: XXXXXXXSUCONZ01.DES.* Additional .DES ASCII points abstract with descriptions of ALL points used for the project would be named similarly. *Sample name: XXXXXXXSUCONZ02.DES*

.PTS – ASCII file with final control network control values for latitude, longitude, ellipsoid height, grid state plane northing, grid state plane easting, elevation, scale factor, and convergence of all marks. Coordinates should be provided for all points in the survey network. This file should include a note of datums, adjustment tags, and geoid model used. The file should include a note of what marks were held for horizontal and vertical. A .pts file is only required for new survey control networks, and all values in the file should reflect final GNSS network adjustment values. Sample name: *XXXXXXXSUCONZ01.PTS*

.VCE – Trimble Business Center file format set to the correct datum and geoid with all control points from the .ift file imported and set to control quality. There should be no other data (e.g., vectors) in the file. Sample name: *XXXXXXXSUCONZ01.VCE*

.JXL – Trimble job exchange file exported from the .VCE file above. Sample name: *XXXXXXXSUCONZ01.JXL*

.ZIP – Files comprising all information and data for the project that have been compressed. Sample name: *XXXXXXXSUCONZ01.ZIP*

.TXT Read-Me files – Text Read-Me files explaining the submitted files and explanations of how the survey was performed, including notes of datums and adjustments used, geoid, and what marks were held. *Sample name: XXXXXXXSURMEZ01.TXT*

CHAPTER 5

ENGINEERING SURVEYS

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5.1 Introduction

Engineering surveys provide the base mapping of existing physical features for designers on Montana Department of Transportation (MDT) projects. These surveys show planimetric features and define the 3D shape of the existing ground. Point features are represented by symbols, and line features are represented by varying types and widths. The 3D shape of the existing ground typically is defined by a triangulated irregular network (TIN), sometimes referred to as a digital terrain model (DTM).

5.2 Survey Scoping Meeting

For internal MDT projects, the survey request form will define project needs. For consultant projects, needs should be confirmed during the survey scoping meeting. The goals of the survey request form and survey scoping meeting include:

- Confirming the extents of mapping where complete topography is expected to be provided.
- Identifying any areas within mapping extents not expected to include full topography.
- Confirming whether utilities are required as part of the survey.
- Delineating what will be mapped by a traditional ground survey and what, if anything, will be mapped by remote sensing methods including terrestrial lidar, mobile lidar, or airborne photography and/or lidar (Chapter 7: Remote Sensing).

Engineering surveys must use approved project control or establish secondary control in conformance with Chapter 4: Control Surveys.

5.3 Project Equipment Selection

Engineering surveys have specific equipment needs. Project equipment selection should be tailored to meet the project's design needs. Additional information on equipment can be found in Chapter 3: Equipment.

5.3.1 Total Station and GNSS Surveys

Total station engineering surveys should be used for features benefitting from higher local relative accuracy, such as:

- Bridge components.
- Hard surface features (sidewalk, curb and gutter, pavement, etc.).

High-multipath environments are also well suited for a total station. These environments include:

- Treed areas.
- Canyons or steep topography.
- Vertical structures (buildings, tanks, or silos).

- Underneath bridges.

Figure 5-1: High-multipath environments are well suited for using total stations

Global navigation satellite system (GNSS) engineering surveys are appropriate for:

- Soft surface mapping.
- Relatively low-multipath environments.

Areas where GNSS is proposed for hard surfaces should be identified during scoping or on survey request forms.

Figure 5-2: Example of a low-multipath environment

5.3.2 Alternative Methods

Alternative methods to a traditional ground survey may be considered when there is a clear advantage to using them. Alternative methods include terrestrial laser scanners, mobile lidar, echosounders, unmanned aerial vehicles (UAVs), and future emerging technologies. MDT is flexible in using alternative methods, but the resulting data needs to meet department standards and project objectives. Non-typical equipment may benefit a variety of situations.

Terrestrial laser scanners may be appropriate for engineering surveys of:

- Roadways and intersections with high-speed or high-frequency traffic.
- Bridge structures and substructures.
- Miscellaneous complex features benefitting from a high level of detail such as manholes and vaults.

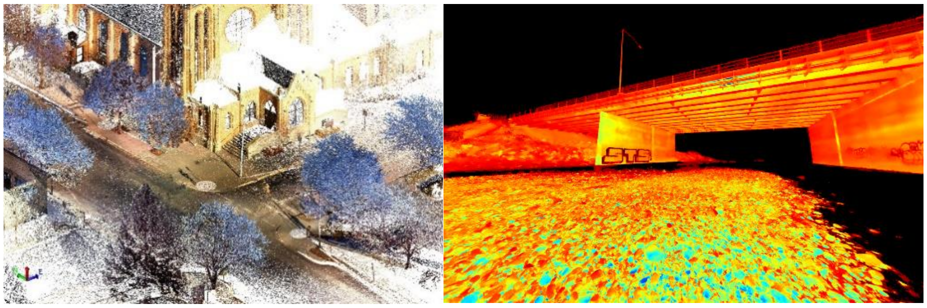

Figure 5-3: Scanner-derived point clouds of an intersection (L) and a bridge (R)

Mobile lidar may be considered for long corridors benefitting from high-density information or for areas that cannot otherwise be occupied safely by personnel or equipment.

Engineering surveys involving point clouds should consider the needs and capabilities of the end user(s) of the survey and if simpler methods can provide the necessary information. Processing time may be intensive when extracting features from lidar point clouds. See Chapter 7: Remote Sensing for standards.

Echosounders allow surveyors to gather bathymetric survey data unattainable through traditional methods like a wading survey with GNSS or a total station. Single-beam echosounders can be paired with either GNSS or a total station to determine depths of rivers or lakes. Multibeam or side-scan echosounders may be useful in a situation requiring a detailed point cloud of the river or lake floor (e.g., for detailed bridge scour assessments). Chapter 5: Engineering Surveys provides more information.

UAV sensors are highly variable in cost and performance. The suitability of a UAV for any project depends on the sensor collecting data. Photogrammetry-type UAVs excel at capturing current high-resolution orthoimagery but may be less reliable than other mapping options for developing a surface model in areas with significant vegetation. Depending on the sensor deployed, lidar-type UAVs can be useful for mapping large areas with vegetated cover. See Chapter 7: Remote Sensing for standards.

During scoping, all alternative methods should provide expected accuracies and identify methods for controlling and checking the dataset.

5.4 Engineering Survey General Standards

The following standards relate to conducting engineering surveys for MDT use.

5.4.1 Control

Engineering surveys must use approved project control or establish secondary control in conformance with the procedures in Chapter 4: Control Surveys.

Check shots should be performed during every survey to verify instrumentation is set up properly. Total station setups should perform a check to the backsight control point and a check to a foresight control point. Errors may indicate further investigation into prism constants and target heights or disturbed control points. GNSS setups similarly should check into a control point to verify antennae heights and that the GNSS integer ambiguity has been solved correctly. Errors may indicate a poor GNSS environment or set-up errors.

Control positions tend to deteriorate with time from forces like freeze/thaw and plate tectonics. Analyzing control checks for reasonable deterioration requires professional judgment informed by specific project requirements and general professional experience.

Secondary control may be added when existing project control cannot be occupied. Secondary control can be established by meaning coordinates determined by GNSS observations from two or more control points. If GNSS cannot be used to establish secondary control, a total station can be used to establish the secondary control by performing a closed traverse.

Alternatively, secondary control may be determined by performing a three-point resection. Errors in the resection and control checks should be analyzed for reasonableness using professional judgment and should conform with guidance in Chapter 4: Control Surveys.

5.4.2 Feature Codes

Feature codes are descriptive text fields collected for all points that represent an abbreviated version of a given feature such as EOP for edge of pavement or BOB for bottom of bank. The feature code can be used by field and office software to determine:

- Whether the item is a point feature or linear feature.
- Whether the point will be included in the existing ground surface model.
- Whether linear features are breaklines and cannot be triangulated across in the existing ground surface model.

Table 5.1 shows a sampling of feature codes. All feature codes and a description of how they should be surveyed can be found in MDT's Feature Code Summary. MDT also provides a Feature Code Reference Sheet that shows all codes and a short description in a concise format.

CATEGORY	CODE	FEATURE	POINT OR LINE	DTM OR NON-DTM	BREAKLINE?	COLLECTION POINT(S)
Drainage	CULVI	End of culvert invert	Line	Non-DTM		At the end of a pipe or invert, at both the end treatment and pipe end when end treatments are present.
Misc.	CORE	Core/drill hole	Point	Non-DTM		At the center of the geotechnical boring hole.
Natural	BOB	Bottom of bank (natural slope)	Line	DTM	Yes	Along the bottom of the bank.
Natural	GRND	Ground shot or mass point	Point	DTM		On the existing surface of a random ground shot or at the center of the mass.

Table 5.1: Sampling of Feature Codes

A point can use multiple feature codes; for example, SW CONC could be used where a sidewalk intersects with another concrete slab. Multiple lines of features with the same name can be run by adding a numerical suffix to a feature code; for example, EOP01, EOP02, and EOP03 are used in Figure 5-4 to represent the multiple edge of pavement points.

Line control codes can be used following feature codes to start and stop lines and draw curves. MDT uses the following control codes:

- BL – Begin line.
- EL – End line.
- SSC – Start smooth curve.
- ESC – End smooth curve.
- CL – Close line.

Figure 5-4 shows the application of control codes BL and EL to begin and end lines.

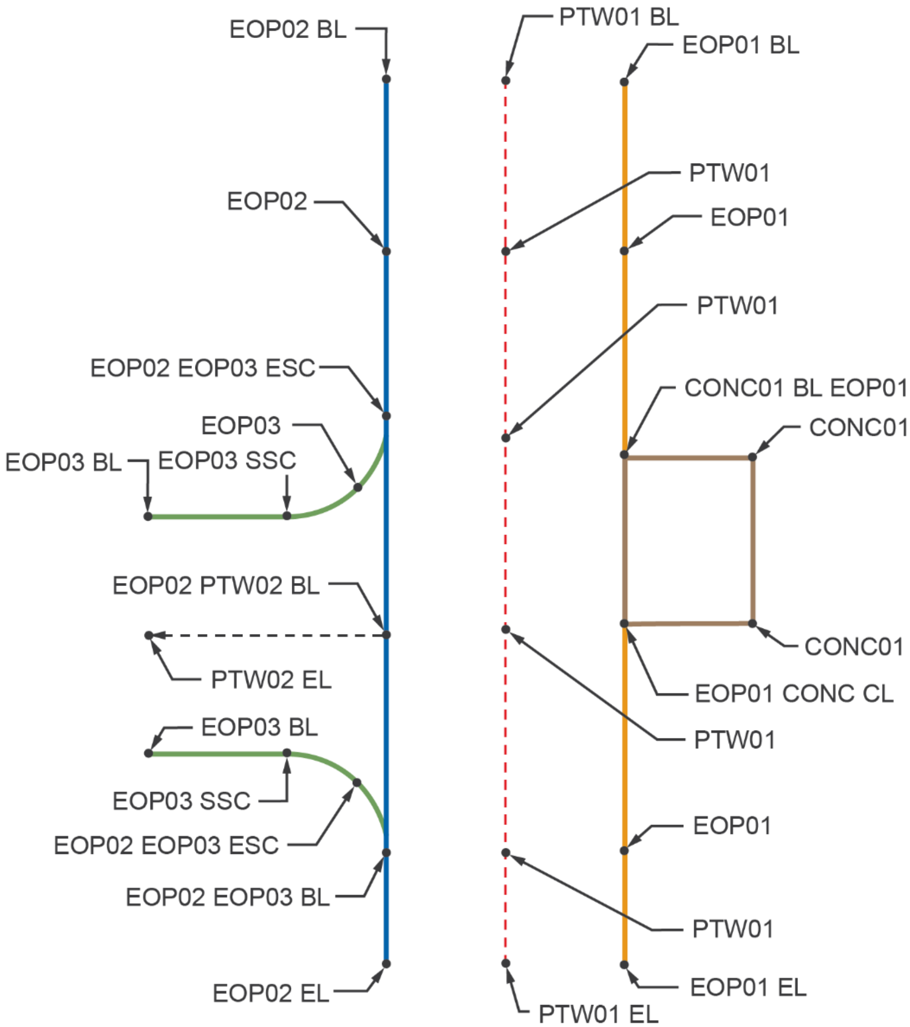

Figure 5-4: Sample feature coding showing line control codes and double coding

5.4.3 Point Attributes

Depending on the feature code entered, a point may have one or more attribute fields providing supplemental data about a feature. For example, collection of the feature code ABUT at a bridge abutment will give the user an option to enter an attribute to define the width of the abutment. The feature code TREE will give the user options to enter species, height, and trunk diameter. When collecting points with attributes, only one feature should be surveyed for each point. See MDT's Feature Code Summary for attributes available for each feature and Section 5.5.4.1.2 for detailed information on culvert attributes.

5.4.4 Point Numbering and Spacing

USER TIP:* *Careful use of the active map screen while mapping can prevent drafting errors, including crossing breaklines.

Engineering surveys should use unique points numbered 50,000 and up. Point spacing generally is dictated by terrain and feature complexity. Points should be located no farther than 25-ft. apart and at a sufficient density to define features horizontally and vertically.

5.4.5 Breaklines and Surfaces

Breaklines are 3D lines that add definition to an existing ground surface by controlling the behavior of the TIN model or DTM. A TIN will not allow a triangle edge to cross a breakline. Figure 5-5 shows an example of a crossing breakline.

Some DTM features (e.g., GRND or ground shot) are only points with a surface elevation at the point location. Breaklines force the surface model to interpolate between two or more DTM points.

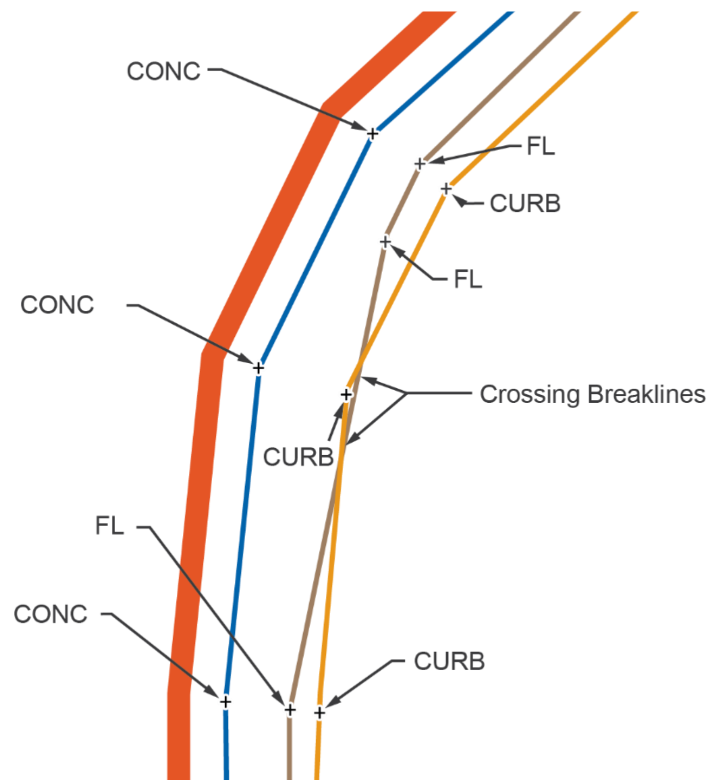

Figure 5-5: Crossing breaklines

5.4.6 Curvilinear Features

Curved features should either be surveyed into short chord segments or as smooth curves using line control codes.

5.4.7 GNSS Observations

In engineering surveys, GNSS observations should be three or more epochs in length. Continuous real-time kinematic methods are generally only allowed for bathymetric surveys but may be considered for projects during the survey scoping meeting if there is a project for which it is well suited (e.g., a project with an urgent timeline and relatively consistent flat topography).

5.5 Hydraulic Surveys

Survey personnel perform hydraulic surveys as a specialized subpart of engineering surveys. Hydraulic surveys at MDT comprise data for both hydraulics – the study of fluids through engineered systems – and hydrology – the study of the behavior of water in its environment. These surveys collect data for designers to understand how the hydraulics and hydrology of existing systems may be impacted or altered during project design engineering. Each project has unique needs and may require coordination between survey, hydraulic design, transportation design, structural design, and aerial mapping providers. For internal MDT projects, survey requests are included in the project Location Hydraulic Study Report (LHSR). For consultant projects, needs should be confirmed internally with the consultant's hydraulic design team and externally during the survey scoping meeting.

5.5.1 Survey Scoping Meeting and Hydraulics

The hydraulic survey request forms or survey scoping meeting should identify:

- Where ground survey is expected to be needed for hydraulics.
- What type(s) of hydraulic ground surveys are needed (e.g., cross sections, structure survey, channel topography).
- Where remote sensing is expected to be used for hydraulics (e.g., where aerial mapping may be used to model cross-sectional topography).
- Where heavy vegetation and/or trees are expected to render aerial mapping (and usually GNSS receivers) less effective.

Existing as-builts and other types of annotated maps may be helpful for documenting hydraulic survey scope needs and can be distributed to field personnel in advance of the survey.

On complicated internal projects, MDT Hydraulics provides survey personnel with a computer aided design drawing (CADD) file showing desired cross section locations and areas to be mapped to develop a TIN (see Section 5.5.3).

5.5.2 Local Information

Field personnel should document and report to hydraulic design any interactions with local sources that could provide useful information pertaining to hydraulics. This includes but is not limited to information related to:

- High water events.
- Overtopping locations.
- Existing deficiencies.
- Irrigation operation and performance.

5.5.3 Topographic Data

Hydraulic ground surveys are developed into the project DIMAP. The DIMAP is an electronic drawing prepared in MDT's current drafting design software that comprises exclusively hydraulic survey data, including points, linear features, and, where required, a surface terrain model in the form of a TIN. The purpose of a DIMAP TIN is to fill in the locations where ground surface data are needed for hydraulics.

Ground surveys of topography for hydraulics generally should conform with Engineering Survey General Standards. Points of emphasis include:

- Hydraulic survey points should be observed from primary or secondary project control points.
- Hydraulic survey areas are frequently treed or obscured overhead by bridge decks. GNSS should not be used in high-multipath environments.
- Topography should represent significant horizontal and vertical changes in features.
- Survey points for a contiguous survey area along a cross section or along a profile should have a maximum point spacing of 25-ft. or as defined by the hydraulic engineer.

Hydraulic topographic surveys should be produced to meet the American Society of Photogrammetry and Remote Sensing (ASPRS) vertical positional accuracy class of 15 cm, which, for reference, is the closest equivalent mapping class in the current standards to the former National Map Accuracy Standard's 1-ft. contours. See the current ASPRS Positional Accuracy Standards for Geospatial Data and Chapter 7: Remote Sensing for additional information.

Photographs can be especially useful for documenting conditions of hydraulic structures like culverts and bridges. Photo files should be indexed with a corresponding point number in the survey. The point number should be in delivered photo file names and should represent the feature being surveyed.

5.5.4 Culvert Surveys

Culverts convey water under roadways, approaches, and other transportation infrastructure and play a critical role in managing stormwater runoff and flood prevention. Field personnel are responsible for collecting survey data points at culverts and for collecting culvert attribute information.

5.5.4.1 Standard Culvert Information

Data points are collected by GNSS or total station observations. Attributes are observed in the field and related to individual points using data collection software.

5.5.4.1.1 Common Data Points

Field personnel should survey all culverts identified by hydraulic design in the hydraulic survey request form. The common data points associated with this feature are thalweg or flow line (feature code: FL), centerline of roadway (PTW), top of culvert/pipe (CULVT), and end of pipe/culvert invert (CULVI). Flow line observations should terminate/begin at the pipe end or pipe end treatment; they should not connect through the culvert. In silt- or sediment-filled pipes, flow line should be observed where the water truly flows (i.e., at the lowest point of the top of sediment or silt through the pipe).

Field personnel should dig out culvert inverts covered with sediment, debris, snow, or ice to observe the true culvert invert. See the MDT Feature Code Summary documentation for the most up to date guidance on feature coding for culverts.

5.5.4.1.2 Culvert Attributes

Culvert attributes provide end users with data to complete design functions such as hydraulic modeling to evaluate when an existing or designed culvert would be expected to flood.

Pipe Size

The pipe size attribute is expressed in inches.

Circular pipe size refers to the inner diameter of a pipe. Typical circular pipe sizes include each 3-in. interval between 12-in. and 24-in. and each 6-in. interval between 24-in. and 84-in.

Non-circular pipe sizes refer to an equivalent inner diameter for arch pipes and structural steel plated pipes (SSPPs). Arch pipes are typically described in terms of span (cross-sectional width) and rise (cross-sectional height).

The relationship between span, rise, and equivalent diameters can change depending on corrugation type. For a complete list of potential sizes encountered and their equivalent diameters, see the MDT Hydraulics Manual: Chapter 11.

USER TIP:
If a culvert is filled with sediment, survey the flow line at the sediment elevation and dig out the culvert to survey the culvert's invert.

Pipe size should conform with the survey data points collected for CULVI and CULVT, accounting for wall thickness. For example, a circular corrugated metal pipe (CMP) with a diameter of 18-in. should have an elevation difference close to 1.5-ft. between CULVI and CULVT observations because corrugated metal pipes typically have a thin pipe wall. A circular reinforced concrete pipe (RCP) with a diameter of 24-in. and a pipe wall thickness of 3-in. should have an elevation difference close to 2-ft., 3-in., or 2.25-ft. Be alert for changes in pipe wall thickness as pipe sizes increase. Verify the surveyed pipe size conforms with typical type sizes and is not due to a damaged culvert end.

Pipe Material

Pipe materials are commonly referred to by acronyms like RCP and CMP. See Table 5.2 for a list of common materials and their acronyms. For a complete list of pipe materials, see Table 11.4-1 in the *MDT Hydraulics Manual*.

Care should be taken to properly differentiate between corrugated metal pipes and structural steel-plated pipes. Corrugated metal pipes are fabricated in sections of whole pipe, whereas plated pipes are built from corrugated plate sections that are bolted together to form the desired shape. See Table 5.1 at the end of the chapter for photo samples of pipe materials.

ACRONYM	PIPE MATERIAL
CMP	**C**orrugated **M**etal **P**ipe, circular shape, commonly found
CMPA	**C**orrugated **M**etal **P**ipe, **A**rch shape
HDPE	**H**igh-**D**ensity **P**oly**e**thylene, also referred to as corrugated plastic pipe
PVC	**P**oly**v**inyl **C**hloride – uncommon in hydraulics but occasionally encountered
RCB Single	**R**einforced **C**oncrete **B**ox, single cell
RCB Double	**R**einforced **C**oncrete **B**ox, double cell
RCP	**R**einforced **C**oncrete **P**ipe, circular shape, commonly found
RCPA	**R**einforced **C**oncrete **P**ipe, **A**rch shape
SSPP	**S**tructural **S**teel **P**lated **P**ipe, circular shape
SSPPA	**S**tructural **S**teel **P**lated **P**ipe, **A**rch shape
OTHER	Miscellaneous pipe materials otherwise not listed

Table 5.2: Pipe Materials and Their Acronyms

Pipe Coating

A pipe coating is a continuous flexible layer added to a pipe to improve longevity. Options for pipe coating attributes are:

- Polymeric – Bituminous or non-asphalt polymeric coatings.
- Metallic – Galvanized (zinc or iron) or aluminum.
- None.

Culvert End Treatment Type

Culvert end treatments protect culverts and provide transitions to surrounding terrain. Options for culvert end types are:

- FETS – Flared end terminal section.
- Square – A square end treatment.
- RACET – Road approach culvert end treatments look like a partial culvert extension with horizontal metal bars or pipes placed perpendicularly along the top of the partial culvert extension.
- Beveled.
- RCB Sloped – RCB with a sloping end section.
- RCB Flared – RCB with wingwalls that are level or sloping.

See Table 5.3 for photo examples of end treatments.

Edge Protection

Edge protection refers to material placed at the pipe edge generally to prevent erosion and increase longevity. Options for this field include:

- Concrete.
- Riprap.

- Other.

If riprap or concrete edge protection is present, the perimeter extent of the protection should be surveyed as a linear feature.

End Damage

End damage is a yes/no field determined by assessing whether the pipe has been damaged. Additional information describing the damage (e.g., SQUISHED) may be added to the comment attribute field.

Amount Embedded

Amount embedded refers to the amount of material present inside the pipe. Assess embeddedness on a scale of 0% full to 100% full in 25% increments. A surveyed point (typically coded FL) should be observed at the top of the embedment.

Usage Type

Usage type is an attribute assessed in the field based on the context of a culvert's environment. Usage type attribute options are:

- Drainage – Culverts used to convey drainage waters.
- Irrigation – Culverts used to convey irrigation waters.
- Stock pass – Culverts used to move stock across transportation corridors.
- Drainage stock pass – Culverts used for both stock and drainage, often located at a low spot in the road profile.
- Other – Wildlife crossings, pipe sleeves, etc.

Comment Field

Comments are a text field used for pertinent data, including:

- Descriptive text like SQUISHED can help explain discrepancies between pipe diameters and culvert survey shots.
- Pipe corrugations or pipe gages may be helpful if they can be ascertained by field personnel. See MDT Hydraulics Manual for additional information on corrugations and gages.

Culvert Photos

Field personnel should take photos at each culvert and index them by point number or as-built stationing. A well-composed photo can help office personnel confirm attributes were collected and entered correctly. Each culvert should have photos taken of the following features:

- Inlet and outlet of culverts.
- Upstream and downstream views of channel leading to and from culvert.
- Locations of scour or erosion near the culverts or in road ditches.
- Overtopping location (roadway, ditch bank, or basin divide).

Photos of culverts should feature environmental context of the culvert ends but be close enough to identify pipe type and approximate diameter. Review photos in the field to confirm they are not poorly lit and/or poorly focused.

5.5.4.2 Thalweg

The thalweg, is the lowest elevation of a watercourse. This term is used to determine the boundary between two deeds separated by a watercourse. Surveyed thalweg points are recorded as thalweg and are not the same as flowline (FL/FLU) used with a culvert topographic mapping..

5.5.4.3 Cross Sections

Hydraulic cross sections are a linear series of points that sample topography, typically perpendicular to streamflow or flood flows. Cross sections should be surveyed for all culverts 36-in. or greater in diameter and for any additional culverts identified by hydraulic design.

Channel cross sections should, at minimum, include the following:

- Survey one channel cross section perpendicular to flow upstream and one downstream. Channel cross sections typically include significant grade breaks (GB), tops of bank (TOB), bottoms of bank (BOB), thalweg (FL), and edge of water if present (EDGEWAT) at water surface elevation. Survey edge of vegetation where seasonally disturbed by streamflow if discernible (MISCL EDGEVEG or MISCP EDGEVEG). Include cross sections of nearby ditches or drainages that run parallel to the channel for your culvert.
    - The downstream cross section should be placed at the most constricted nearby portion of the watercourse.
    - Areas with scour downstream should have a cross section at the scour location and at the most constricted nearby portion of the watercourse.
- To prevent cross section feature codes from crossing on the data collector map or during processing, use begin line or end line commands.

5.5.4.4 Existing Roadway Centerline

Provide a roadway centerline profile (cross section) to delineate the potential overtopping location(s). Provide shots at 25-ft. (10m) intervals along the existing roadway centerline a minimum of 400 ft. (120m) left and right of the pipe, unless otherwise noted in the hydraulic survey request. Survey of the roadway centerline is necessary to find the overtopping location such as a vertical sag located within the floodplain. Include a shot at each end of any solid barrier rail if present.

5.5.4.5 Upstream and Downstream Structures

Survey the footprint and floor of structures upstream and downstream that could be affected by culvert-related flooding. Structures may include residences, outbuildings, hay barns, or similar improvements. These structures are typically identified during scoping by hydraulic design personnel, but field personnel should also be observant of structures near culverts that could be damaged by floodwaters if the culvert were to fail to convey water.

5.5.4.6 Springs

Survey freshwater springs when present and contributing to a culvert.

5.5.4.7 Water Surface Elevations and High-Water Marks

Survey the water surface elevation if water is flowing through a culvert at the time of the survey. Survey both sides (EDGEWAT) at the same interval as thalweg observations.

Survey high-water marks (HIWATER) when present. These may include stains on edge protection, rust lines on the culvert, or debris lines at the culvert inlet. Take a photo that clearly identifies where the high-water mark was surveyed.

5.5.4.8 Scour and Erosion

Survey evidence of erosion when present near culverts. This may include scour holes, erosion of fill, and channel headcutting. Scour holes form where turbulent water erodes the streambed and forms a depression. Erosion of fill around pipe ends may be identified by irregular and uneven surfaces with a lack of soil cover. Channel headcutting can be identified by notable change in the thalweg elevation that deviates from what would appear to be the normal profile of the channel.

Erosion can threaten the longevity and effectiveness of culverts, making it a key concern for the hydraulic design team. Use photos and point feature codes to document erosive conditions.

5.5.4.9 Major Detailed Culvert Surveys

Hydraulic design may identify large culverts that will require a higher-level detailed survey, similar to what is required for bridges.

In addition to standard culvert information, detailed culvert surveys also may require survey of:

- Detailed topography near the structure consistent with Section 5.5.3.
- A bank-to-bank survey of the channel 500 ft. upstream and 1,500 ft. downstream, including thalweg, top of bank, edge of vegetation, edge of water, bottom of bank, and grade breaks.
- Cross sections perpendicular to flood flow at locations identified by hydraulic design. Cross sections should include ground (feature code: GRND), top of bank (TOB), bottom of bank (BOB), thalweg (FL), edge of vegetation (MISCP EDGEVEG), edge of water (EDGEWAT) at water surface elevation, and grade breaks (GB). Use “begin line” or “end line” control commands to prevent linear features from forming.
- Longitudinal roadway profile consistent with Section 5.5.4.4.
- One or more cross sections over the roadway and parallel to the pipe.
- The field-assessed overtopping point. The overtopping point refers to the location at which water would spill over a given structure, often a roadway bank or basin divide. The overtopping point can be visualized by imagining the culvert being plugged or overwhelmed with water,

causing water to stack up and fill like a bathtub. At what point would water on the inlet side begin to spill over to the outlet side? The overtopping point is often – but not always – at the center of the road and above the top of the culvert. Overtopping points can be difficult to identify in the field, and collecting multiple points or profiles may be necessary.

5.5.5 Bridge Surveys

Bridge surveys are used to develop models to predict the behavior of water over a range of flow conditions. Bridge survey and detailed culvert survey requirements are similar, but bridges require additional survey and observation of specific features.

5.5.5.1 Topography

Like a detailed culvert survey, bridge surveys require collection of detailed topography near the structure consistent with Section 5.5.3. This includes the area under the bridge, which will almost always require its own total station setup. See the Secondary Control section of Chapter 4: Control Surveys.

Depending on the project and its hydraulic modeling approach, the topographic area requiring survey for hydraulics may extend hundreds of feet or more away from a given structure. Shifts in a project roadway alignment or project temporary detour design can also extend hydraulic topography needs. Lidar, photogrammetry, and ground survey – or a combination of them – may be necessary to collect this data.

5.5.5.2 Bridge Details

This section provides a list of required survey items for bridge surveys. Figure 5-6 illustrates many of the required features.

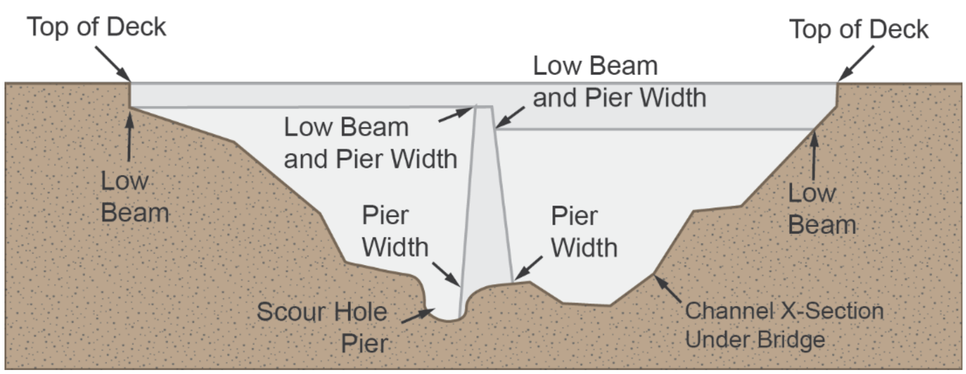

Figure 5-6: Bridge detail illustration

5.5.5.2.1 Low Beam

Low beam (feature code: LOWBEAM) refers to the lowest part of the bridge structure that can potentially impede the flow of water. The low beam is often, but not always, the bottom of the girders that rest on top of piers and abutments at the bridge ends. Survey significant vertical changes in the low chord at each pier.

Low chord should be surveyed on both upstream and downstream bridge faces.

5.5.5.2.2 Pier Locations and Sizes

Survey pier locations and provide their dimensions, including the pier cap itself. Data collector routines can also be used to compute the center of the pier. Piers or piles that are driven at an angle (instead of vertically plumb) are referred to as battered. Collect survey data to define the batter angle of such piers. Sketches or photos, ideally with surveyed points superimposed, may be useful to help hydraulic design personnel understand how the surveyed points relate to the overall structure.

5.5.5.2.3 Left and Right Abutments

Survey the inside top edge of abutments (ABUT) and or retaining walls. Note its width as an attribute. See Figure 5-7.

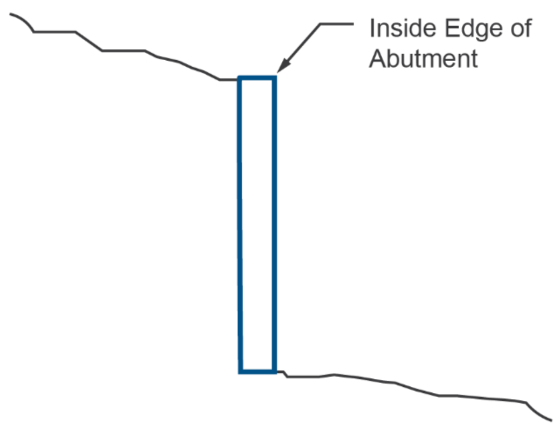

Figure 5-7: Survey of an abutment's inside edge

5.5.5.2.4 Cross Section Under Bridge

One cross section should be placed intentionally under the bridge near roadway or rail centerline. Code these points using their standard feature code descriptions like TOB, BOB, etc.

5.5.5.2.5 Bridge Deck Corners

BRCOR is a linear feature code that should represent the shape of the bridge. Collect enough points to represent irregular shapes and curvature.

5.5.5.2.6 Bridge Centerline Profile

Survey roadway profile (PTW) to the extents desired by hydraulic design. On superelevated roadways, survey the high and low side of the roadway prism using the appropriate physical feature such as edge of concrete, edge of pavement, or shoulder.

5.5.5.2.7 Nearby At-Risk Structures

Hydraulic design may identify private structures upstream and downstream of bridges that could be at risk of flooding. Survey the footprint and floor.

5.5.5.3 Channel Survey

Survey thalweg (feature code: FL), top of bank (TOB), edge of vegetation (MISP EDGEVEG), edge of water (EDGEWAT) at water surface elevation, bottom of bank (BOB), and grade breaks (GB) 500 ft. upstream and 1,500 ft. downstream of the culvert unless specified by the hydraulic engineer.

5.5.5.4 Cross Sections

Survey cross sections at the following locations:

- Locations identified by hydraulic design.
- Immediately upstream and downstream of the bridge, outside of the bridge and roadway fill slopes.
- At significant changes in drainage topography (e.g., if one side of overbank terrain changes from steep cliffs to a flat floodplain).

Include points at thalweg (FL), top of bank (TOB), edge of vegetation (MISCP EDGEVEG), edge of water (EDGEWAT) at water surface elevation, bottom of bank (BOB), and grade breaks (GB). Cross sections should be perpendicular to flood flow and should extend laterally above the maximum possible flood elevation. Cross sections where aerial mapping is not available can be 2,000 ft. or greater in length.

5.5.5.5 High-Water Marks

Survey high water marks (e.g., stains on piers or abutments, debris lines on edge protection, rust lines on culvert, or debris lines at the culvert inlet). These points can be coded HIWATER.

5.5.5.6 Scour and Erosion

Survey significant scour holes observed at bridges by collecting ground points, thalweg points, and grade breaks if discernible.

Survey channel head cutting where the thalweg profile deviates from the apparent normal slope of the channel. Collect bank-to-bank topography (TOB, BOB, FL, GRND, GB) to encompass the upstream and downstream ends of the vertical change.

5.5.5.7 Existing Riprap

Survey the perimeter of bridge riprap (feature code: RIPRAP). Riprap can be considered large rock, concrete rubble, and gabion baskets filled with rock.

5.5.5.8 Photos

Photos should be indexed by point number and/or with direction and location of each photo somehow documented. Photos should be included from the following locations:

- From bridge looking upstream and downstream.
- At all cross sections showing overbank vegetation and channel characteristics.
- Looking upstream and downstream in channel.

- Looking across floodplain from end of cross section.
- Piers (if applicable) and abutments; both upstream and downstream faces.
- Additional structures upstream or downstream of roadway bridge.
- Locations of scour or erosion visible during survey.
- Locations of high water surveyed shots.
- Unique items such as irrigation features crossing channels, head cuts, natural drops in channels, etc.
- Roadway left and right of the bridge.

5.5.6 Bathymetric Surveys and Echosounders

Channel surveys or cross section surveys for bridges or culverts may be too deep to wade and survey with a traditional GNSS pole or total station rod. A single-beam echosounder paired with a GNSS receiver or total station can be used to complete cross sections and channel surveys for most projects with areas too deep to wade.

Real time kinematic (RTK) and/or post-process kinematic (PPK) observations are acceptable for echosounder surveys. Follow the echosounder manufacturer's guidance for calibrating the echosounder, and overlap the echosounder with traditional data from GNSS or total station at multiple locations to verify echosounder is working correctly.

Alternative bathymetric remote sensing tools such as multibeam or side-scan echosounders may be deployed for projects requiring a higher level of detail at the channel floor and piers. These alternative tools and the methods to check and ensure their quality should be discussed as part of project planning and scoping, including during the survey scoping meeting. Additional deliverables may be required for these surveys and should be confirmed before conducting the field survey.

5.5.7 Irrigation Surveys

Given their importance to landowners before and after transportation projects, MDT strives to maintain or improve the function of nearby irrigation facilities and/or systems. Complete survey data facilitate an accurate assessment of existing conditions, which in turn aids the design processes that follow.

5.5.7.1 Irrigation Culverts and Bridges

Irrigation bridges and culverts generally should be surveyed consistently with drainage counterparts in Sections 5.5.4 and 5.5.5, respectively. Hydraulic design should identify areas where irrigation structures need detailed topographic surveys. Detailed topographic surveys should be completed consistent with Section 5.5.3.

Irrigation structures are frequently attached to a headwall or other transition structures; define such structures using feature codes like ABUT (top of wall or abutment) and CONC (concrete edges).

Surveys should include operating water surface upstream and downstream of the structure. Note the time and date of operating surface elevations in the feature code (e.g., EDGEWAT 06MAY23 12P).

5.5.7.2 Ditch Surveys

The following ditches should be included:

- Ditches connected to a bridge or culvert identified for survey by hydraulic design.
- All ditches within 250-ft. of the roadway.
- Any ditch running parallel with the roadway that could be disturbed by construction.

For structures identified by hydraulic design, survey the ditch 150 ft. upstream and downstream, maintaining the standard 25 ft. maximum point spacing or what was defined by the hydraulic engineer. Survey the complete ditch prism, including thalweg, top of bank, bottom of bank, grade breaks, and edges of water at water surface elevation.

Beyond these limits, hydraulic design personnel may request extended thalweg observations to determine the hydraulic profile of the channel. The extended thalweg area could be thousands of feet in length.

5.5.7.3 Cross Sections

Hydraulic design may identify cross sections to supplement ditch surveys. Cross sections should be placed at locations where the section is a good representation of the channel and where the channel shape or profile changes significantly. Cross sections should cover how the ditch bank ties into adjacent terrain, but hydraulic cross sections generally do not need to be as long as drainage cross sections.

If a road is present at the irrigation structure, survey a cross section of the road centerline profile if the road is crowned or flat. If the road is superelevated, survey both the high and low features of the roadway.

5.5.7.4 Structures

The following irrigation structures should be surveyed if they are either within the right-of-way or identified by hydraulic design as needing survey:

- Division structures.
- Check structures.
- Drop structures.
- Head gates attached to small sections of pipe.
- Slide-gates.
- Flumes.
- Pivots.
- Alfalfa valves.

- Pipe risers.
- Air vents.
- Flow Measurement Weirs.

The following information is required at irrigation structures:

- Material type – Documented in field notes or using point coding or attributes.
- Survey points to define:
  - Top of structure shape.
  - Shape of entire structure floor.
  - Wingwalls and headwalls with wall thickness noted using either point coding or attributes.
  - Ditches leading to and from the structure.
  - Water stains on structures that may identify standard operating water surface elevation.
  - Key elevations including the bottom of the structure, flowlines, headgates inverts, and weir elevations.

5.5.7.5 Water Surface Elevations and High Water Marks

Water surface elevations and high water marks for irrigation pipes and structures are typically showing constant operating water surface elevations. These are one of the most important items that can be surveyed for irrigation designs.

The most significant difference between drainage pipe/bridge crossings and irrigation crossings is the estimated water that the crossing will see. Flows at drainage crossings are estimated based on multiple drainage area characteristics, and they are typically highly variable. Flows at irrigation crossings are usually quite constant and can be estimated based on known water rights and in system controls like head gates.

Therefore, all water surface elevations and water marks on pipes, bridges, or irrigation structures need to be surveyed. These water surface elevations are critical in calibrating designs and providing adequate conveyance capacity for new irrigation pipes and structures. Water surface elevations surveyed along the ditch are also used to develop a water surface profile to help lay out a new pipe, especially if the ditch is very flat. See Figure 5-8 for examples of high water marks.

Figure 5-8: Irrigation highwater marks

5.5.7.6 Photos

Photos should be taken at all irrigation structures surveyed. See Section 5.5.4.1.2 for culvert photos required and Section 5.5.5.8 for bridge photos required. Add photos at locations where ditch characteristics change.

5.5.8 Urban Storm Drainage

Urban storm drain systems collect, convey, and manage stormwater runoff. Survey data of these systems are used to understand which areas contribute water to the system and how much water the system can handle.

5.5.8.1 Contributing Area

Contributing area refers to the catchment area within a watershed that contributes runoff to a specific point of interest like a storm drain inlet or reservoir.

Hydraulic design may identify areas requiring ground survey to analyze the contributing area. These areas could include anticipated aerial mapping voids or areas beyond project mapping (e.g., distant curblines).

5.5.8.2 Manholes, Inlets, and Pipes

At manhole or inlet structures identified by hydraulic design, perform the following:

- At curb inlets, survey the inlet rim elevation at the flow line of curb at the middle of the inlet, and note the grate size.
- Survey middle of lid or grate for manholes and all non-curb inlets. For grates, indicate the grate size.
- Determine manhole or inlet invert elevations with a measuredown, or survey the invert location directly with GNSS or a total station.
- Note size and shape of structure barrel.
- Note compass direction of pipes within the structure.
- Note pipe material, shape, and diameter within the structure.

Noted items need to be collected and transmitted to the design team. This can be accomplished with handwritten field notes or partially prefilled forms of the required items.

5.5.8.3 Other Storm Features

Hydraulic design may identify additional miscellaneous storm features requiring survey, such as slotted drains, curb openings, infiltration basins, and water treatment devices. For slotted drains, survey the extents of the drain and note the dimensions and quantity of the slotted portion(s) of the inlet. At curb openings, survey the back of curb and flow line of curb to define the opening width and height.

Infiltration basins are shallow ponds that allow surface water to enter permeable soils and pass through to the groundwater aquifer. Where present, survey the extents of the pond with enough survey data to conform with Section 5.5.3.

Water treatment devices may appear similar to inlets or manholes. These devices remove surface contaminants via filtration (e.g., media treatments) or physical processes (e.g., vortex separation unit). Collect data at water treatment devices in a similar fashion to other manholes and inlets. Take measuredowns to document the elevations of any devices. Contact hydraulic design personnel to determine if any additional survey data are needed.

5.5.8.4 Outfalls

An outfall is a structure where stormwater runoff from a storm drainage system is discharged into natural drainage. Survey the following:

- Invert and top of outfall pipe.
- Channel downstream of outfall until it reaches natural drainage, including top of banks, bottom of banks, thalweg, and grade breaks.
- Riprap perimeter.
- Water surface elevation of the receiving waters. Note time and date. Identify any highwater elevation at the outfall.

Note pipe size and material using point attributes and/or field notes.

5.5.8.5 Detention Ponds

A detention pond is an artificially created basin designed to temporarily store stormwater runoff. A detention pond outlet structure regulates the discharge to a downstream drainage system. Survey the pond using grade breaks and ground shots to define the extents and volume. At the outlet structure, survey the following:

- Invert of structure floor.
- Top of structure.
- Invert and top of all pipes at the structure.
- Invert and top of outlet at ends of the pipes.
- Grate size and dimensions including opening areas.

Use survey points to define the dimensions of any weirs or note the weir dimensions with reference to a survey point. Note structure material using feature codes or field notes.

5.5.8.6 Proposed Outfall

Hydraulic design may identify areas requiring topographic survey where a proposed new outfall is expected. These areas require a topographic survey that conforms with Section 5.5.3.

5.5.8.7 Photos

Take photos and index them by point number at the following features:

- Outfall structures, pipes, and ditches.
- Downstream of outfall pipe.
- Drop inlet grates.
- Drop inlet interiors.
- Curb inlets or slotted drains.
- Detention ponds, infiltration basin.
- Detention basin structures.
- Manhole interiors (remove lid, do not enter).

5.6 Deliverables

MDT standard format files and brief descriptions for engineering surveys submitted by consultants in AutoCAD Civil3D format are as follows:

- XXXXXXXDIMAPZ01.DWG – 3D Autodesk file.
- XXXXXXXDIDTMZ01.XML – LandXML file of surface.
- XXXXXXXDINNEZ01.CSV – CSV with attributes (point ID, northing, easting, elevation, feature code, attributes).
- XXXXXXXDINNEZ01.TXT – ASCII file with all culvert information (point, northing, easting, elevation, type, coating, usage, size, culvert end, end treatment, edge protection, damaged end, condition, comment).
- XXXXXXXDINNEZ02.TXT – ASCII file with all hydraulic information (point, northing, easting, elevation, feature).
- XXXXXXXDIGPAZ01.ZIP – Compressed file of all information and data files for the submittal.
    - Include a photos subfolder with all hydraulic-related photos, indexed by point numbers.
    - Include a field notes and sketches subfolder containing all notes and sketches that pertain to hydraulics and hydrology.

- XXXXXXXDIRMEZ01.TXT – Text (Notepad) file explaining the submitted files and how the survey was performed.

5.6.1 Support Information

MDT requires the delivery of dated and neatly organized original field notes, including critical field measurements, as a PDF file, named logically with the project UPN.

MDT requires the delivery of calibration reports, data collection files, raw files, and office processing files. See Chapter 3: Equipment for calibration report requirements.

5.6.2 File Size Limitations

File size standards are not provided due to the difficulty in establishing limitations that will not be out of date during the use of this manual. However, it is essential to consider the practicality of the file sizes for the computers and/or devices that will be utilizing them. Keep in mind MDT is a large organization with a constrained budget that may have some users operating older computers.

PHOTO	**TYPE**	**END TREATMENT**
	CMP	FETS
	CMP	Square
	CMP or SSPP	Bevel
	CMP	Square
	CMPA	Bevel
	RCP	Square

PHOTO	TYPE	END TREATMENT
	RCP	FETS
	RCPA	Square
	RCPA	FETS
	RCB	Bevel
	RCB Single	RCB Flared
	RCB Double	RCB Sloped

Table 5.3: Pipe Types and End Treatment

CHAPTER 6

CADASTRAL SURVEYS

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6.1 Introduction

The primary purposes of cadastral surveys are to retrace and monument the record location of the existing right-of-way and to locate and establish the required property controlling corners. At the Montana Department of Transportation (MDT) there is no distinction made between right-of-way obtained by easement or fee.

All cadastral surveys will be completed under the direct supervision and responsible charge of a land surveyor licensed to practice in the state of Montana. All cadastral surveys will conform to all applicable state statutes Montana Code Annotated (MCA) and rules in the Administrative Rules of Montana (ARM).

6.2 Cadastral Project Scoping

For consultant projects, the extents and requirements of the cadastral survey are defined during the survey scoping meeting with input from the land survey manager, the MDT Right-of-Way Bureau, and the district surveyor. Internal MDT projects are defined by the district surveyor and district right-of-way designer.

Cadastral surveys are defined, subsequently, as Level 1, Level 2, or Level 3 to allow for flexibility in addressing project needs.

This activity also requires coordination with the project design team to understand the range of potential improvements in a project and how the improvements will affect right-of-way needs.

6.3 Cadastral Survey Levels

The extents of any cadastral survey should be confirmed in the survey scoping meeting and/or project scoping documents for consultant projects. Internal project extents can be confirmed via internal forms or processes determined at the district level. Extents should be expressed in terms of right-of-way stationing and/or roadway milepost. Graphic depictions of extents also may be helpful, particularly in retracements involving multiple sets of right-of-way plans with mixed stationing.

All levels of survey require a Montana-licensed professional surveyor in responsible charge of the project.

Level 1 surveys should be limited to projects with no planned improvements within 2-ft. or less of the existing right-of-way boundaries.

6.3.1 Level 1

Level 1 surveys require the lowest level of effort. These surveys are for well-defined projects with no planned right-of-way acquisition. These surveys may be used to develop construction permits.

For Level 1 surveys, MDT expects the project cadastral surveyor to obtain the most recent and applicable set(s) of right-of-way plans and survey the location of existing right-of-way monuments within the survey extents.

No new monuments are set, and nothing is recorded. The cadastral surveyor prepares linework in the project SUCAD (survey cadastral) drawing to current MDT Computer Automated Design and Drafting (CADD) standards. Since Level 1 surveys rely on less evidence, the boundaries established by Level 1 surveys should be considered less reliable by end users relative to Level 2 or Level 3 surveys. Level 1 surveys should be limited to projects with no planned improvements within 2-ft. or less of the existing right-of-way boundaries.

No additional research is required beyond the right-of-way plans.

6.3.2 Level 2

Level 2 surveys may be the appropriate approach when the project right-of-way needs are unclear or when it is obvious that monumentation set in the near term for a retracement survey could be destroyed by construction.

In addition to right-of-way monuments, Level 2 surveys also search for and survey:

- Adjoining property corners on the subject right-of-way line(s).
- Right-of-way reference pins.
- PLSS section and quarter corners.

Level 2 surveys require full cadastral research and analysis for the project extents. They do not, however, require reestablishment of missing right-of-way or Public Land Survey System (PLSS) monuments or the preparation of a Certificate of Survey for the entire extents. Instead, Level 2 surveys follow this process:

- Preparation of linework in the project SUCAD drawing to current MDT CADD standards.
- Coordination between Right-of-Way Bureau, the project manager, and the cadastral surveyor takes place to target locations where right-of-way is needed.
- Development of a Certificate of Survey only at the targeted locations.
- Reestablishment of missing monuments only at the targeted locations with corner records prepared for PLSS corners where required by statute.

For consultant projects, Level 2 surveys may benefit from a phased approach to scoping, in which the greater area requiring Level 2 survey is scoped first, followed by an amendment to identify the targeted locations that require a Certificate of Survey and monumentation.

6.3.3 Level 3

Level 3 is the highest effort of cadastral survey and is considered a full retracement survey for the project extents. Level 3 surveys are ideal for large projects with a high degree of clarity at the start of the project in terms of what ultimately will be needed for right-of-way. Projects with widening or realignment are good examples of Level 3 effort.

All relevant corners are searched for and surveyed. The surveyor sets any missing corners at right-of-way breaks, right-of-way geometry changes, and

PLSS survey crossings. A Certificate of Survey is prepared and recorded for the entire project extents, and corner records are prepared where required by statute.

6.4 Point Numbering

Assigned point ranges are as follows:

- 200-299: PLSS section, 1/4, 1/16, center of section, miscellaneous other PLSS corners.
- 300-599, 700-999: Right-of-way corners, property corners, computational points.
- 50,000+: Topographic points relevant to the cadastral survey. Coordinate with the project manager to avoid duplicating points with other activities using the same point range.

6.5 Cadastral Feature Codes

Table 6.1 provides a sampling of the commonly used cadastral-related feature codes. Table 6.2 at the end of the chapter provides all cadastral feature codes.

CODE	FEATURE
COMP	Computed point, nothing set
EQ14F	East quarter corner, found
MDTRW	MDT right-of-way, set
MDTRWF	MDT right-of-way, found (not concrete)
NQ14F	North quarter corner, found
RWCONC	Concrete right-of-way marker, found
RWCONCD	Damaged concrete right-of-way marker, found
RWRPF	Right-of-way reference pin, found
SECF	Section corner, found

Table 6.1: Commonly Used Cadastral Feature Codes

6.6 Level 1 Limited Research

Level 1 cadastral surveys only need to obtain a copy of applicable and current MDT right-of-way plans for the project extents. MDT right-of-way plan search options can be found at this link. MDT Right-of-Way Bureau classifies projects as open (ongoing) or closed (completed). Because of the complexity of right-of-way negotiations, it can take years after a project is ostensibly completed before it is closed.

The Right-of-Way Bureau has two project classifications: "open" for ongoing projects and "closed" for those that are complete.

If the project does not involve a highway corridor with typical MDT right-of-way interests (e.g., a preliminary survey of an adjoining residential parcel for early acquisition), then the Level 1 survey should obtain the most recent recorded map depicting the subject parcel(s) or boundaries of concern.

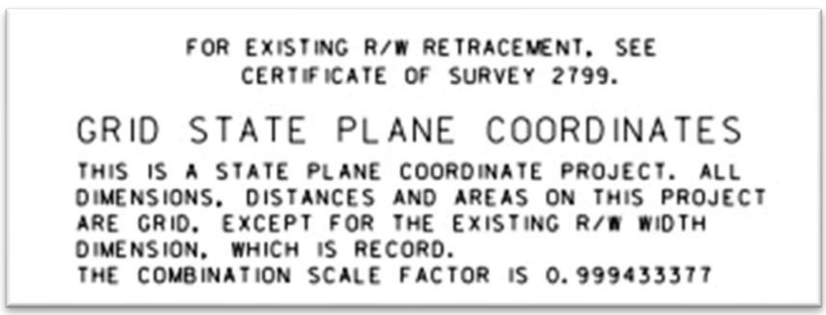
6.7 Full Cadastral Research

MDT Level 2 and 3 cadastral surveys are retracement surveys that require full cadastral research efforts. The following sections identify the most common documents gathered but should not be considered an exhaustive list of all potential sources of documentary evidence.

6.7.1 All Right-of-Way Plans

Larger projects and projects with complex right-of-way geometry often require multiple sets of highway and/or railroad right-of-way plans. Right-of-way plans with lines labeled “existing” or “ex.” indicate there may be additional right-of-way plans that may have information pertaining to the project.

Prior to the widespread adoption of Global Positioning System (GPS) by surveyors in the 1990s, right-of-way plan distances were expressed in ground distances. In the GPS era, however, it became more practical to use a common datum (the State Plane Coordinate System) on MDT projects. State plane projects do not use ground distances. Stationing, offsets, and coordinates on state plane projects are all grid distances. Right-of-way plans on the state plane grid will have a note describing the coordinate system and will provide a combined scale factor (CSF) for computing ground distances. Figure 6-1 is an excerpt from a right-of-way plan sheet that identifies the CSF used for that specific set of right-of-way plans.


FOR EXISTING R/W RETRACEMENT, SEE
CERTIFICATE OF SURVEY 2799.

GRID STATE PLANE COORDINATES

THIS IS A STATE PLANE COORDINATE PROJECT. ALL
DIMENSIONS, DISTANCES AND AREAS ON THIS PROJECT
ARE GRID, EXCEPT FOR THE EXISTING R/W WIDTH
DIMENSION, WHICH IS RECORD.
THE COMBINATION SCALE FACTOR IS 0.999433377

Figure 6-1: Combination scale factor note

Railroad right-of-way plans are also accessible at MDT’s plan search site. Retracing railroad right-of-way may require research and/or field coordination with any rail companies operating in the existing railroad right-of-way. Retracing railroad right-of-way is its own specialized field, but at a minimum the railroad right-of-way surveyor should be aware of the following:

- Railroad plans typically use the chord definitions for degree of curvature, not arc curve definitions.
- Railroads usually do not monument their right-of-way edges and breaks.
- Railroad plans on the plan search site may be incomplete or out of date.

6.7.2 Right-of-Way Acquisition Documents

Right-of-way acquisition documents in the forms of deeds and easements define where MDT rights-of-way were acquired and what type of interest was acquired. Rights-of-way granted to MDT by deeds are considered fee-simple interests, meaning MDT has full ownership of those properties without restrictions. Rights-of-way granted to MDT by easements give MDT the right to use the land but do not transfer ownership of the land to the department.

Retracement surveys should distinguish between MDT fee interests and easement interests, but for operational purposes, MDT does not treat the two differently. Rights-of-way acquired by easement interests are still expected to be monumented as part of monumenting the existing right-of-way during Level 3 surveys.

Defining the location of right-of-way interests begins with close examination of the right-of-way acquisition document(s) for the project area. MDT has a right-of-way plan search that allows users to search for easements, deeds, and agreements by multiple search fields such as federal highways project identification number; owner/grantor name; or section, township, and range. A successful search will provide the surveyor with information (e.g., document number or book and page) to search for the documents at the appropriate county courthouse.

Surveyors can expect to find a wide range of approaches in the legal descriptions of acquisition documents, but the acquisition documents, not the right-of-way plans, control what interests were conveyed. Surveyors cannot assume the acquisition documents conform totally with the right-of-way plans because sometimes that is not the case.

Acquisition documents may use the following approaches to describe interests conveyed:

- A description that references right-of-way plans totally.
- A description that references a centerline, baseline, staked line, projected line, or other reference line shown on right-of-way plans.
- A description that, for whatever reason, is not related to the right-of-way plans.

If the surveyor is retracing a description that references a centerline, baseline, or other reference line, then the goal of the retracement will be to reestablish the reference line by using all available evidence in the field. Typically, the best evidence of a centerline or baseline is the right-of-way monumentation on both sides of the road for the totality of the geometry in question. For example, a retracement survey of a small portion of a long highway tangent would evaluate evidence on both sides of the road for the entire length of the tangent, not just along the small portion needed.

If an acquisition document cannot be found at the county courthouse, the surveyor can request the information from the MDT Right-of-Way Bureau by routing the request through the appropriate project manager(s). Requests for documentation from the Bureau should be a last resort after exhausting all local search options.

In the event the retracement survey cannot find any acquisition documents for areas in the rights-of-way currently occupied and maintained by MDT, the retracement survey should identify the areas as clearly as possible on the appropriate survey deliverables.

6.7.3 Maps and Deeds of Adjoining Properties

The surveyor should gather the following for all properties adjoining the MDT right-of-way:

- Subdivision plats and their amendments.

- Certificates of survey and their amendments.
- Documentation of city or county road rights-of-way that adjoin or intersect the project (e.g., dedication via plat, road petitions, and county survey reports).
- The current vesting deed for each adjoining landowner.

If MDT or a consultant has worked in the vicinity, there may be existing retracement Certificate(s) of Survey recorded. Some county clerks may not have a great system for indexing these types of surveys, so it can be useful to ask the clerk if they are aware of any special collections of documents related to roads or railroads. City and county public works and roads departments also can be useful for researching where road records, such as road petitions, are located.

6.7.4 PLSS Documents

Right-of-way plans typically provide detailed information at the locations where the right-of-way crosses a section line. Figure 6-2, for example, shows a baseline crossing the section line and provides the stationing (412+26.2) of the baseline at the crossing with distances to the section corner and quarter corner.

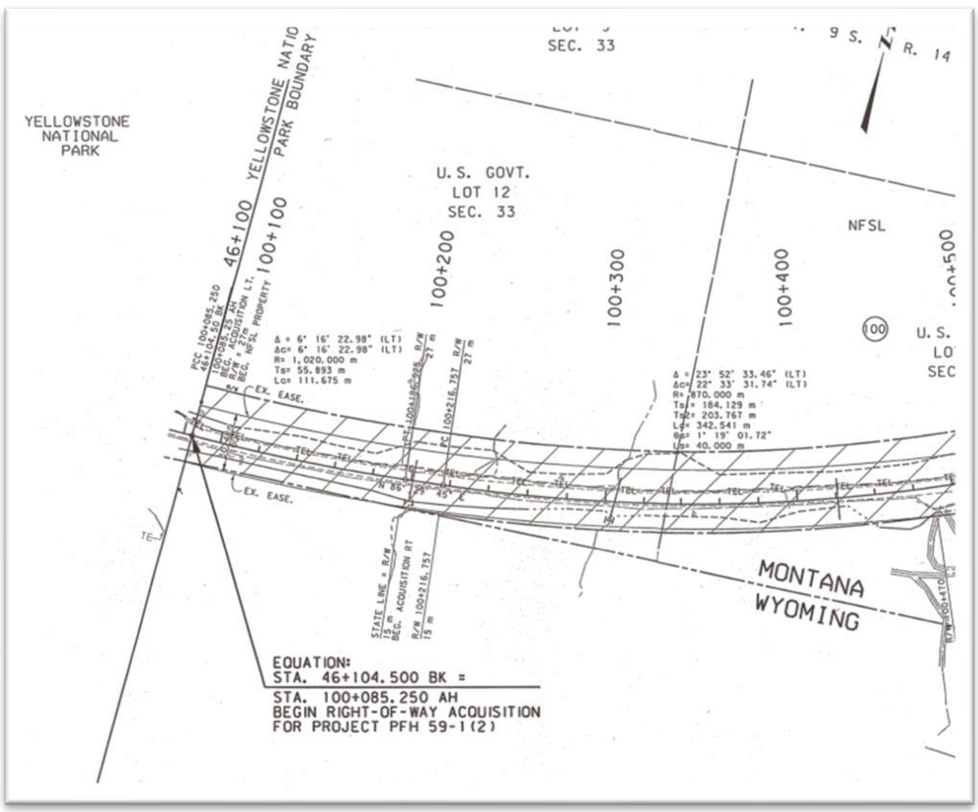


Figure 6-2: An excerpt of MDT right-of-way plans

Retracement surveys should survey all section line crossings. Subdivisional line crossings may be necessary if:

- There is a break in the right-of-way on the subdivisional line. Deed research may be necessary to determine if the subdivisional line is required.

- The retracement is necessary to determine the location of land acquired by MDT when such land is defined by subdivisional lines.

To prepare for the field survey of required PLSS corners, the cadastral surveyor should have all pertinent documents, including:

- Field notes from the General Land Office (GLO) or successor federal agency.
- Survey plats from the GLO or successor federal agency.
- Existing certified corner records providing evidence of a corner.
- Subdivision plats, Certificates of Survey, and amendments providing evidence of a corner.

6.8 Field Work Evidence Collection

Some of Montana's older roadways may not have been monumented at all. Some projects may have been monumented, only to have some or all monuments destroyed by subsequent construction activities. In cases like these, the physical roadway, section line crossings, and other improvements shown on plans may be some of the best evidence available to determine the right-of-way location.

Right-of-way acquired from the 1910s to the 1980s was typically monumented with concrete right-of-way markers. These are square concrete posts that project out of the ground, as shown in Figure 6-3. Some may have their tops damaged or broken off. Typical retracement practice in Montana is to survey the center back of the concrete post at its highest undamaged point.

Figure 6-3: Concrete right-of-way marker

The cadastral surveyor searching for concrete markers should also search for right-of-way reference pins, typically located approximately 2-4-ft. inside the right-of-way from the marker. Right-of-way reference pins from this era are typically 5/8-in. smooth rods. See Figure 6-4.

Figure 6-4: Right-of-way reference pin

Right-of-way acquired from approximately the 1990s to present was typically monumented with aluminum caps on 5/8-in. rebar. There may or may not be reference pins present with aluminum caps. Right-of-way reference pins from this era may be 5/8-in. smooth rods, 5/8-in. rebar with a plastic cap affixed, or a rebar that has had its cap shorn off.

Adjoining property corners intended to be on the right-of-way in the project area should be included in the survey.

Working on or near railroads requires coordination with the railroad, including performing all mandatory railroad safety compliance. Culverts, bridges, and other items shown on railroad plans can be useful for analyzing railroad right-of-way.

At all required PLSS corners, the surveyor should collect evidence to determine whether to accept or determine a position based on evidence found in the field or consider it destroyed.

6.9 Field Work Observations

All monuments necessary for the survey must be observed at least twice from two different control points. Provided different bases are used, there is no time separation requirement for observations.

If project control was established using the Montana State Reference Network (MTSRN), then the MTSRN is also acceptable for cadastral observations. The MTSRN surveyor should perform two observations at least two hours apart.

Single base solutions and network solutions are both acceptable but should be consistent with how project control was established.

Global navigation satellite system (GNSS) observations should be 180 epochs or more in length.

Total station observations can be completed with any combination of three points as instrument point and backsight point to perform two or more observations.

Differences in observations should be less than 0.10-ft. in horizontal distance. Judgment may be applied by the surveyor to accept greater differences in observations if the monuments have low positional uncertainty (e.g., a GLO stone or bend point in a damaged post). It is not necessary or desirable to mark GLO stones with a center punch or other carvings to indicate the location tied.

6.10 Cadastral Survey Monumentation

At the conclusion of Level 2 and 3 cadastral surveys, the cadastral surveyor may need to reset missing or substandard monumentation. All survey monumentation should comply with current statutes and administrative rules in Montana, and survey markings on caps should be consistent with the current Bureau of Land Management (BLM) *Manual of Surveying Instructions*.

In soft surface areas, MDT right-of-way is typically monumented with 2-in. aluminum caps on 5/8-in. x 24-in. rebar. Hard surface areas are monumented with brass plugs or similar, countersunk slightly below grade. Materials should be ferrous, or magnets should be used during installation. Caps should be marked with the point number shown on the related Certificate of Survey.

PLSS corners shown on Certificates of Survey should meet the state's uniform standards for monumentation. If a new monument is required in soft surface areas, MDT prefers a 30-in. flared-end aluminum monument with 3 ¼-in. cap. In hard surfaces, MDT prefers a 3 ¼-in. cap set firmly in non-shrink grout just below the road surface to avoid damage from plowing. See Figure 6-5.

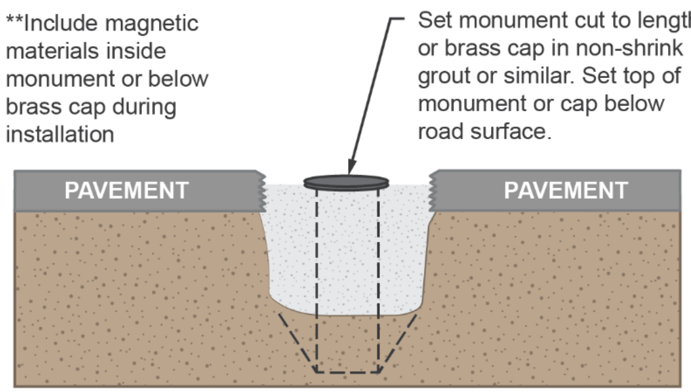


Figure 6-5: Monument installation in paved roadway

If the PLSS corners are expected to be destroyed by future construction, the surveyor should set two or more reference monuments. Lines drawn from reference monuments to the monument should intersect as close to perpendicularly as is practical. The surveyor can use similar materials for reference monuments as right-of-way monuments: a 2-in. aluminum cap on 5/8-

in. x 24-in. rebar in soft surfaces or a hard surface plug. Reference monuments should be stamped RM with a distance to the corner.

The cadastral surveyor should use ferrous materials or magnets during installation of right-of-way and PLSS monuments. This may include placing ferrous objects like rebar inside aluminum flared-end monuments or placing small magnets during installation of brass plugs.

New corners requiring stakeout should be surveyed from a project control point or the MTSRN, conforming with how control was established for the project. All new corners requiring stakeout require at least two observations. The cadastral surveyor should perform the first observation when setting the point; the second observation is used as a check.

Project control GNSS observations should be performed from two or more base locations. Each GNSS observation should be at least five epochs in length.

If a total station is used to set the monument, any combination of three project control points as backsight and instrument point are acceptable to set and then check the monument.

In the event project control is inadequate for setting monuments (e.g., in a treed area without line of sight to a project control point), secondary control points can be established and used to perform the required observations.

Differences in observations relative to the stakeout design coordinate should be less than 0.05-ft. in both the northing and easting.

6.11 Right-of-Way Analysis

Using all available research and field evidence, the surveyor should use judgment to reestablish the highway centerline or baseline and all other right-of-way controlling lines in the project area. These lines are developed in the SUCAD drawing prepared to current MDT CADD standards.

When retracing areas featuring reference monuments and concrete right-of-way markers, consider the following:

- The concrete posts were typically set by a contractor, intended to be at a uniform distance from the reference pins.
- The reference pins were typically set by the surveyor with a higher degree of care.
- If the surveyor observes high variability between reference pins and their distances to concrete posts, the reference pins themselves may be better evidence for establishing right-of-way centerlines or baselines.

As would be expected, newer right-of-way plans on the state plane grid label grid bearings, whereas older plans used a basis of bearings specific to each project.

For performing distance-related calculations and computations, the surveyor should use the appropriate CSF consistent with project control activities.

Ultimately, the legal description in the acquisition document controls the right-of-way location. Surveyors need to be particularly diligent in reviewing acquisition documents to properly locate changes in right-of-way widths, also referred to as right-of-way breaks. Most right-of-way breaks have been designed to accommodate a cut or fill slope, but in some cases, breaks may have been placed on a property line or subdivisional section line. In the occasional case of a break being described to a property line or subdivisional line, the location of the property line or subdivisional line would control the right-of-way location instead of secondary evidence such as stationing.

If the right-of-way description references a baseline or other reference line with an offset distance, the typical survey approach is to establish an equitable baseline from surveyed monumentation on both sides of the corridor for the entire length of the subject tangent or curve. Reference pins and right-of-way markers typically control the longitudinal location of the right-of-way breaks and geometry changes, but there are some exceptions such as the example above where the breaks would be placed on the 1/16th line because of the legal description referencing the 16th line.

6.12 Certificate of Survey and Corner Records

The Certificate of Survey should be prepared in accordance with Montana law and local jurisdictional regulations on as many sheets necessary to adequately depict the retracement. It should include:

- Reference to control points used and their coordinate values. If the MTSRN was used, describe the solutions used (e.g., single base vs. network and which station was used).
- Complete listing of all horizontal coordinate points used in the Certificate of Survey with points labeled by their surveyed or computed number. The coordinate listing should provide the horizontal datum and adjustment tag.
- A sheet depicting PLSS corners and retraced PLSS lines. Small projects may be shown on a single sheet.
- Adjoining properties with their current vesting deed.
- Identification of areas lacking documentation of right-of-way acquisition or having otherwise ambiguous right-of-way documentation.
- Documentation of the CSF(s) used and the survey's basis of bearings (Montana State Plane Coordinate System with appropriate datum and adjustment tag).

Where required by statute, the surveyor should prepare and record Certified Corner Recordations.

6.13 Deliverables

Level 1 surveys have a single submittal with relatively limited deliverables. Level 2 and Level 3 cadastral surveys have a draft submittal, followed by MDT reviews as needed, and ultimately end with a final submittal of recorded documents with recording information. MDT expects to review the survey prior to consultants recording documents related to the retracement.

6.13.1 Electronic Deliverables

For electronic files, all levels of survey should submit the following:

- CADD file of the cadastral survey prepared to current MDT standards. Sample name: XXXXXXXSUCADZ01.[file extension]. This sample name reflects the first consultant file of this type (Z01) submitted for a project with a UPN of XXXXXXX.
- Data collector files and survey office processing software files, named logically at the discretion of the surveyor.
- PDF of field notes for all survey activities, named logically at the discretion of the surveyor.
- Supporting data/calculations and right-of-way plans used, named logically at the discretion of the surveyor.

Level 2 and Level 3 surveys require the following additional electronic files:

- PDF of Certificate of Survey. Sample name: XXXXXXXSUCADZ01.PDF. Additional sheets numbered Z02, Z03, etc. Recorded copy with document information required with final submittal.
- PDF of Corner Recordations. Sample name: XXXXXXXSUCADZ0#.PDF. Can be numbered after last certificate of survey sheet. Recorded copies with document information required with final submittal.
- Coordinate text file of points shown on the Certificate of Survey. Sample name: XXXXXXXSUCADZ01.TXT. comma delimited point, northing, easting, elevation, feature, description.
- Coordinate text file of all points surveyed during cadastral activities. Sample name: XXXXXXXSUCADZ02.TXT. comma delimited point, northing, easting, elevation, feature, description.
- .ZIP Compressed file of all information and data files for the project. Sample name: XXXXXXXSUCADZ01.ZIP.
- .TXT Text read-me file explaining the submitted files and how the survey was conducted. Sample name: XXXXXXXSURMEZ0#.TXT
- Supporting data/calculations.
- Supporting research documentation. Subdivision plats, Certificates of Survey, existing corner records, existing easements, existing deeds, existing right-of-way plans, existing railroad right-of-way plans (cropped to area of interest), and federal and agency notes and plats.

CODE	FEATURE
16C	Sixteenth corner, calculated
16F	Sixteenth corner, found
16S	Sixteenth corner, set
C14C	Center of section, calculated
C14F	Center of section, found
C14S	Center of section, set
CCC14E	Calculated closing corner, east side only
CCC14N	Calculated closing corner, north side only
CCC14S	Calculated closing corner, south side only
CCC14W	Calculated closing corner, west side only
COMP	Computed point, nothing set
EQ14C	East quarter corner, calculated
EQ14F	East quarter corner, found
EQ14S	East quarter corner, set
FCC14E	Found closing corner, east side only
FCC14N	Found closing corner, north side only
FCC14S	Found closing corner, south side only
FCC14W	Found closing corner, west side only
MCC	Meander corner, calculated
MCF	Meander corner, found
MCS	Meander corner, set
MDTRW	MDT right-of-way, set
MDTRWF	MDT right-of-way, found
NCCC	North only closing corner, calculated
NCCF	North only closing corner, found
NCCS	North only closing corner, set
NQ14C	North quarter corner, calculated
NQ14F	North quarter corner, found
NQ14S	North quarter corner, set
PPF	Property pin found
RWCONC	Concrete right-of-way marker
RWCONCD	Damaged concrete right-of-way marker
RWRPF	Right-of-way reference pin found
RWRPS	Right-of-way reference pin set
SCC14E	Set closing corner, east only
SCC14N	Set closing corner, north only
SCC14S	Set closing corner, south only
SCC14W	Set closing corner, west only
SCCC	South only closing corner, calculated
SCCF	South only closing corner, found
SCCS	South only closing corner, set
SECC	Section corner, calculated
SECF	Section corner, found
SECS	Section corner, set
WCF	Witness corner, found
WCS	Witness corner, set

Table 6.2: Complete Feature Code List

CHAPTER 7

REMOTE SENSING

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7.1 Introduction

Remote sensing is considered for projects based on size, accuracy requirements, delivery schedule, and resources – both human and aircraft – available at the time of the project. Remote sensing options include mobile lidar, terrestrial lidar, and aerial mapping, all of which can be useful to map areas difficult or dangerous to access on the ground. Depending on the project, the Montana Department of Transportation (MDT) performs aerial mapping using photogrammetry, which uses aerial photographs, or lidar, which uses laser pulses. Some projects may use dual collection with both camera and lidar sensors.

MDT remote sensing activities frequently refer to the ASPRS Positional Accuracy Standards for Digital Geospatial Data. These standards provide helpful guidance and sample calculations.

Determining the desired preliminary mapping extents requires communication between transportation design, hydraulic design, survey, and the aerial mapping provider. Preliminary mapping extents should align with the project scope in terms of where improvements are expected and where mapping is needed for analytical purposes.

MDT remote sensing standards rely on and frequently refer to the American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data. Surveyors and mapping providers should be familiar with the standards.

7.2 Survey Scoping Meeting

For consultant projects with remote sensing activities, the survey scoping meeting should review the following:

- Expected aerial mapping extents and areas requiring supplemental ground surveys.
- Equipment and methods to be used (for both aerial and ground control survey).
- Confirmation of project survey datums, coordinate system, and units.
- Expected accuracies and how the consultant intends to measure and prove accuracies in accordance with ASPRS Edition 2, Version 2.
- Anticipated deliverables.
- Flight plans/control requirements.

The overall aerial mapping plan should be reviewed and approved by the supervisor of photogrammetry and survey or designee prior to beginning remote sensing activities.

7.3 Mobile Lidar and Terrestrial Scanning Standards

MDT accepts the use of mobile lidar and terrestrial scanning to collect survey data when appropriate to meet project needs efficiently. Data processing and data extraction from point clouds can be time consuming, which should be a consideration when collecting point cloud data versus collecting it with GNSS or a total station.

Mobile lidar systems deployed on MDT projects should have an inertial measurement unit (IMU) that meets or exceeds the following specifications:

- Minimum IMU positioning data sampling rate of 100 Hz.
- Maximum IMU Gyro Rate Bias of 1 degree per hour.
- Maximum IMU Angular Random Walk (ARW) of 0.125 degree per √hour.
- Maximum IMU Gyro Rate Scale Factor of 150 parts per million.

7.3.1 Georeferenced Control

All scan data must be referenced to project control and delivered in the project coordinate system and vertical datum. Point clouds observed from a scanning total station on a project control point and oriented to one or more project control backsights do not require any additional post processing.

Static scanners and mobile lidar both typically require targets to georeference the lidar point cloud. Targets can be treated as secondary control (see Chapter 4: Control Surveys). The number of targets required for a static scanner survey requires considering the scan survey area extents, the capability of the scanner and software being deployed, and how much the scan survey will rely on cloud-to-cloud registration versus targeted registration. See Figure 7-1 for typical mobile lidar target sizes and materials.

Terrestrial and mobile lidar target placement requirements are a function of the capabilities of the scanner being deployed. Use judgment to determine adequate targeting to meet the point cloud accuracy standards in Section 7.3.2.

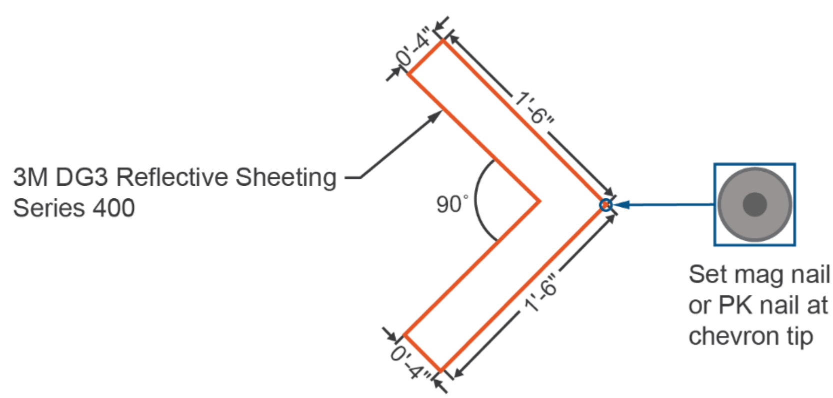

Figure 7-1: Mobile lidar target placement

Processors of point clouds need to produce a geospatial control report that quantifies the amount of error distributed to ground control points (targets) held for georeferencing. Errors for georeferenced control should be smaller than the expected errors of the final dataset deliverables. At least 10 percent of georeferenced targets should be held as checks against the control.

7.3.2 Terrestrial and Mobile Lidar Point Cloud Standards

When mobile lidar or terrestrial lidar point clouds are used to extract significant planimetric features and/or digital terrain model (DTM) surfaces, the point cloud should be classified consistent with Section 7.8.3. Projects in which the point cloud is being used exclusively for a surface DTM may only need classification of ground points.

For accuracy, mobile lidar and terrestrial point cloud datasets should be tested to meet the following standards unless lower accuracy standards are agreed upon internally or in the survey scoping meeting and scoping documents:

- ASPRS 3 cm horizontal positional accuracy class.
- ASPRS 2 cm vertical positional accuracy class.

Accuracies are computed using root mean square error (RMSE) in the horizontal plane. See subsequent sections in this chapter for additional guidance.

If point clouds are used to generate surface data, breaklines should be created consistent with aerial mapping guidance in Section 7.8.2.

7.3.2.1 Checking the Dataset

Checks are performed using global navigation satellite system (GNSS) or total station observations from project control and in conformance with ASPRS guidelines. GNSS should be used only in low-multipath environments.

Scan data obtained from scanning total stations generally is acceptable without additional checks. If the scan data are used to develop a DTM surface, use judgment to perform a number of checks commensurate with the size of the surface developed from the data.

Terrestrial or mobile lidar datasets used to extract significant planimetric features and/or a surface DTM require conformance with check shot guidance from the ASPRS guidelines. Check shots should be distributed evenly spatially and in terms of ground cover and vegetation types.

For scanning projects not used to produce a DTM, use judgment to perform a reasonable amount of RMSE horizontal and elevation checks to a surveyed point's nearest neighbor in the point cloud.

7.4 Flight Planning and Overlap

Required overlap is dependent on terrain and sensors deployed. For aerial photography flown with traditional aircraft and metric camera at a mean altitude over relatively flat terrain, MDT accepts a side overlap of at least 30 percent and an end overlap between 55 percent - 65 percent. In mountainous terrain, side overlap and end overlap can be determined by the aerial mapper based on flying conditions and terrain.

Ultimately, the aerial mapper is responsible for knowing their equipment and acquiring enough overlap to achieve the proposed horizontal and vertical mapping accuracies.

7.5 Ground Control

Ground control is required for aerial mapping projects.

7.5.1 Ground Control Locations

Ground control points should be located:

- Within existing flight plan and targeting guidelines.
- At a safe location to access and occupy with survey equipment.
- On level ground.
- Viewable from the sky.
- Away from areas under trees or power lines.
- Away from tall objects that could cast shadows.

7.5.2 Point Naming

Points should be named consistently with the guidance for aerial mapping points in Chapter 4: 4.4.2 New Aerial Control.

7.5.3 Targeting

Targeting requirements should be coordinated between the aerial mapping provider and survey.

At target locations falling on hard surfaces, paint the target and monument the target location with a small nail or brass plug. At target locations falling on soft surfaces, use plastic material or similar targeting materials and monument the target location with a 5/8-in. x 30-in. rebar with 2-in. aluminum cap. Targeting material should lie as close to the bare earth ground as possible. Trim vegetation as needed.

White targeting may appear washed out on lightly colored surfaces. In such areas, use alternate colors or add contrasting colors to the targeting scheme. See Figure 7-2-2 for MDT's standard aerial targeting scheme.

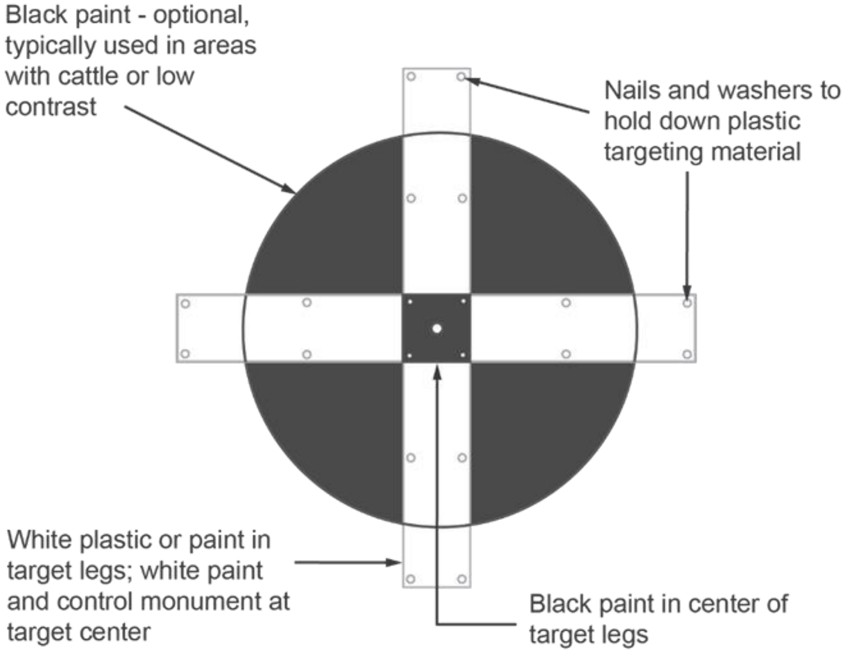

Figure 7-2: MDT standard targeting scheme

7.5.4 Ground Control Point Accuracy

Ground control point accuracy requirements are a function of desired horizontal and vertical accuracies. Accuracy requirements fall into one of two categories:

- If the ground control will be used to generate planimetric data (orthoimagery and/or digital planimetrics) only.
- If the ground control will be used for planimetric data and elevation data.

To compute accuracy requirements, use the Accuracy Requirements for Ground Control Used for Aerial Triangulation or the Accuracy Requirements for Ground Control Used for Lidar in the ASPRS Positional Accuracy Standards for Digital Geospatial Data.

7.5.5 Methods

Depending on the project scope and control plan, ground control point values can be determined by all three methods listed in Chapter 4: 4.9 Horizontal Control:

- A new control network.
- MTSRN control.
- Secondary control.

MTSRN and secondary control methods may require closed loop differential levels to determine the vertical values.

7.6 Photo Identifiable Points

If an area cannot be targeted or a target is lost for whatever reason, aerial mappers may resort to requesting photo-identifiable points (PIDs) from survey. PIDs are natural or artificial features that are well defined and visible from the sky.

PIDs should be surveyed consistently with Chapter 4: 4.9.3 Secondary Control.

7.7 Unmanned Aerial Vehicles

MDT requires the adherence to ASPRS Edition 2, Version 2 standards. Data produced from UAVs are generally subject to the same requirements as data produced from traditional aircraft, including accuracy, check shot, and deliverable requirements. Some differences for UAV mapping include:

- Control for UAVs may comprise a nail and washer or equivalent at the target location.
- Targeting materials and sizes may be modified to suit flight acquisition needs.
- Overlap and sidelap of imagery collected for photogrammetry will generally be a higher percentage than the metric cameras flown by manned aircraft.

Control values for UAV ground control points may be determined using secondary control methods.

7.8 Mapping Standards

The following sections define MDT mapping standards.

7.8.1 Conditions

Sensors should be deployed during ideal conditions as much as is feasible. Rain, snow, fog, or smoke should not come between the sensor and the mapped area during collection.

For photogrammetry projects, images should be collected in conditions that minimize shadows and minimize vegetative cover.

7.8.2 Breaklines and Processing

Breaklines should be developed with spacing sufficient to meet the accuracy requirements of the survey. The distance between vertices should not exceed 5-ft.

At a minimum, breaklines should be created for the roadway prism from borrow ditch to borrow ditch. All lidar points should be omitted from the road surface.

7.8.3 Classification

Point clouds should be classified into ASPRS standard lidar point classes. Projects with datasets used exclusively to generate a DTM surface (no planimetric features) only need to classify ground points and may leave all other points unclassified. Confirm ground-only classification is acceptable during scoping and prior to any acquisition.

7.8.4 Accuracy

Accuracy for mapping deliverables should be expressed in reference to current ASPRS Positional Accuracy Standards for Geospatial Data. These standards include useful definitions, explanations, and sample calculations.

Data are described using a Horizontal Accuracy Class and a Vertical Accuracy Class. Accuracies are computed using root mean square error (RMSE) in the horizontal plane. RMSE errors are expressed in the following components:

- $RMSE_x$ – error in easting.
- $RMSE_y$ – error in northing.
- $RMSE_r$ – error in combined northing and easting ($\sqrt{(RMSE_X{}^2 + RMSE_Y{}^2)}$).
- $RMSE_z$ – error in elevation.
- RMSE 3D- horizontal and vertical combined radial error

All accuracy reports shall conform to the template reports found in ASPRS guidelines.

7.8.5 Vertical Accuracy

Vertical accuracy is to be expressed as RMSEV in both vegetated and non-vegetated terrain. Vertical Accuracy Classes are defined by the associated RMSEV specified for the product..

7.8.5.1 Non-Vegetated Vertical Accuracy (NVA)

Vertical accuracy of unvegetated areas is computed using $RMSE_z$ as those errors are expected to be normally distributed and must meet the accuracy threshold.

7.8.5.2 Vegetated Vertical Accuracy (VVA)

The Vegetated Vertical Accuracy (VVA) has no pass/fail criteria and needs only to be tested and reported as found. If the NVA meets user specifications, VVA should be accepted at the reported accuracy level.

See the ASPRS Positional Accuracy Standards for additional information and sample computations.

7.8.6 Horizontal Accuracy Class

Datasets should be tested to meet ASPRS horizontal positional accuracy classes of ≤ 5 cm and finalized at scoping meeting.

7.8.7 Vertical Accuracy Class

Datasets should be tested to meet ASPRS vertical accuracy classes of ≤ 0.6cm and finalized at scoping meeting.

7.8.8 Check Shots

Check shots are used to assess and verify the accuracy of geospatial data. Refer to the ASPRS Positional Accuracy Standards to determine the proper number and distribution of check shots.

Check shots for horizontal accuracy statement need to be of features identifiable from remotely sensed data, such as concrete corners, traffic striping, and stop bars, or – lacking better options with greater definition – manhole lid centers.

Check shots should be well distributed both across land cover types and geographically across the project. Vertical check shots on soft ground should be performed with a topo shoe. Avoid areas with nearby abrupt vertical changes, and locate check shots in relatively flat spots.

7.8.9 Ground Sampling Distance

Ground sampling distance (GSD) defines the distance on the ground represented by each pixel in an orthophotograph. Refer to the ASPRS Positional Accuracy Standards to guide users through the transition from legacy to modern standards.

Such associations may change in the future as mapping technologies continue to advance and evolve. These Standards do not endorse the use of GSD, map scale, or contour interval to express product accuracy

7.9 Low Confidence Areas

After acquiring data and processing, the aerial mapping provider generates low confidence areas where the ground surface and planimetrics were unable to be mapped at a level to meet the accuracy requirements.

Design personnel and survey personnel coordinate to identify low confidence areas still requiring ground survey to meet the project's needs.

Ground surveys to fill in low-confidence areas should be performed in conformance with Chapter 5: Engineering Surveys.

7.10 Deliverables

Remote sensing deliverables vary depending on if photogrammetry and/or lidar were used.

All aerial mapping deliverables require a map certification file, named XXXXXXXPHCRTZ**.txt. Use language similar to the ASPRS sample statement, adjusting for ASPRS version and project specifics. Refer to ASPRS Edition 2, Version 2, Chapter 7.16 Accuracy Reporting for examples.

Reporting Horizontal Positional Accuracy

- "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) RMSEH Horizontal Positional Accuracy Class. The tested horizontal positional accuracy was found to be RMSEH = __(cm)"

Reporting Non-Vegetated Vertical Accuracy

- "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) RMSEV Vertical Accuracy Class. The Non-Vegetated Vertical Accuracy (NVA) was found to be RMSEV = __(cm)".

Reporting Vegetated Vertical Accuracy

- "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a __(cm) RMSEV Vertical Accuracy Class. The Vegetated Vertical Accuracy (VVA) was found to be RMSEV = __(cm)."

Reporting Three-Dimensional Positional Accuracy

- "This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a ___ (cm) RMSE3D Three-Dimensional Positional Accuracy Class. The tested three-dimensional accuracy was found to be RMSE3D = ___(cm) within the NVA tested area and RMSE3D = ___(cm) within the VVA tested area

Consistent with ASPRS guidance, accuracy statements should be provided in the metadata of delivered files.

7.10.1 Photogrammetry Deliverables

- XXXXXXXPHMAPZ01.DWG – 3D Autodesk file.
- XXXXXXXPHDTMZ01.XML – LandXML file.
- XXXXXXXPHOPHF01.TIF – Georeferenced Digital Orthophoto 300MB or less (as many as required, beginning with 01). The file type for orthophotos is not rigid; JPG2000 or other file types widely used by mapping professionals are acceptable.
- XXXXXXXPHGPAZ01.ZIP – Compressed file of all the information and data files for the project.
- XXXXXXXPHRMEZ01.TXT – Text (Notepad) file explaining the submitted files and an explanation of how the survey was performed.
- XXXXXXXPHCRTZ**.txt – Map certification file.
- Aero-Triangulation final adjusted coordinates, camera station parameter file (if required), and control point mis-closure file. The A-T report will include a narrative summary of the process, problems encountered with control points, and steps taken to resolve the problem and an excel worksheet documenting accuracy statistics and assessment tables for horizontal and vertical errors.

7.10.2 Lidar Deliverables

- 3D Autodesk DWG file – XXXXXXXXPHDTPZF01.DWG.
- LandXML DTM file – XXXXXXXXPHDTMZ01.xml.
- Class 1 Processed, but unclassified - XXXXXXXXPHDTMU01.LAS (corresponding segment number, beginning with 1).
- Class 2 Bare-earth ground – XXXXXXXXPHDTMC01.LAS (corresponding segment number, beginning with 1).
- Class 8 Model Key-point - XXXXXXXXPHDTMM01.LAS (corresponding segment number, beginning with 1).
- LAS title boundary index in AutoCAD format. The index will also include the file name of each LAS file.
- XXXXXXXPHCRTZ**.txt – Map certification file.
- Report detailing the narrative summary of the process, problems encountered, steps taken to resolve problems, and control point error analysis and an excel worksheet documenting accuracy statistics and assessment tables for horizontal and vertical errors.

CHAPTER 8

CONSTRUCTION SURVEYS

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8.1 Introduction

Construction surveys take the design from engineers on Montana Department of Transportation (MDT) projects and put it on the ground. Construction surveys may include:

- Adding project control to complete staking functions.
- Performing staking to guide contractors on locations and elevations of designed features.
- Performing checks to ensure equipment is working properly or verifying tolerances are being met.
- Setting final right-of-way at the end of a project, overseen by a licensed professional surveyor.

Each construction project is unique due to variability in design, contractor operations, and construction equipment deployed. All parties involved with construction layout should be familiar with the current MDT Standard and Supplemental Specifications for Road and Bridge Construction, (MDT Standard Specifications). The MDT Standard Specifications identify typical responsibilities for projects with MDT-furnished staking and for projects with contractor-furnished staking.

The construction contract between a contractor and MDT identifies whether a project will use MDT-furnished staking, contractor-furnished staking, or a combination of the two. The construction contract and some related documents (e.g., plans, specifications, special provisions) prevail over the *MDT Survey Manual* when in conflict.

8.2 Construction Survey Project Scoping Meeting

Prior to construction, a scoping meeting is held to coordinate between design, construction, and survey. Scoping meeting attendees should include the contractor, engineering project manager (EPM), project lead, design engineer, district land surveyor, and district automation specialist.

The scoping meeting should address:

- What data is required for a given project and how the project will be constructed to contract tolerances.
- How the project will be constructed.
- Whether a project will use Automated Machine Guidance (AMG, formally known as machine control).
- Whether stake less slope staking or conventional slope staking or a combination of the two will be used.

- Whether the survey information will be delivered to the contractor, digitally or by using survey notes.

The digital design data will be furnished to Construction by the District Automations Specialist. The Preconstruction Activities define the construction model deliverables that are provided by the Designer to construction.

8.3 Project Control for Construction

USER TIP:
A review of design cross sections prior to placing control can increase the probability of the control lasting throughout the duration of the project.

MDT construction projects use the existing project control and coordinate system. Because years may pass between a project's design phase and construction phase, additional project control is often necessary to facilitate project staking.

If the design is completed in advance of the time in which the additional project control is set, cross sections can be reviewed to place the control in locations that are out of the footprint of the road and will not be destroyed. On some projects, control for aerial mapping alone may be adequate for the design phase, with additional project control set only after the design is completed.

Figure 8-1 shows a partial cross section from an MDT plan set. The dashed line represents the design surface, and the solid line represents the existing ground.

The good location identified is within the project right-of-way and at a location without any cut or fill. The poor location shown is also within the project right-of-way but is in a cut slope that will be disturbed by construction. See Chapter 4: Control Surveys for additional guidance on control point placement, materials to use, and how to determine values for new control.

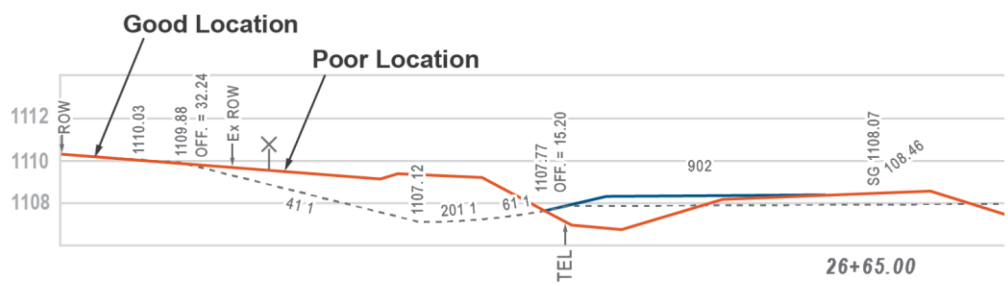


Figure 8-1: Partial cross section from MDT plans for control locations

Construction surveyors should be familiar with Chapter 2: Coordinate Systems and Datums and Chapter 4: Control Surveys. New projects and recent projects are all surveyed on some version of the Montana state plane grid with a geoid model specified. Construction surveyors need to understand the implications of when design and staking are conducted on the grid (typical for most transportation design) or when the design has been scaled by a combination scale factor to true ground distances (typically seen on bridges or other similar structures that require working in true ground dimensions).

8.4 Preservation and Perpetuation of Monuments

Before a project enters an active construction phase, survey should determine how construction activities will impact existing National Geodetic Service (NGS) bench marks, property corners, and public land survey system (PLSS) corners.

NGS bench marks should be reset in accordance with the procedures identified in Chapter 4: Control Surveys section 4.4.4.

Setting of property corners or PLSS corners should be overseen by a licensed professional surveyor and should conform with current Montana statutes and administrative rules.

Contract documentation and right-of-way agreements may specify who is responsible to preserve survey monumentation. If the contractor is responsible, the EPM, contractor, and contractor's land surveyor should coordinate with the district land surveyor prior to destroying or perpetuating any monumentation. If MDT is responsible for preserving monumentation, the EPM should coordinate with the district land surveyor.

8.4.1 Property Corners

Contract documents should indicate if the contractor or MDT is responsible for resetting any property corners disturbed by construction. Right-of-way agreements between MDT and owners also may specify whether certain property corners near the project's present-traveled way will need to be preserved and/or reset in the event of disturbance. Any property corner expected to be destroyed should have a corner recordation of survey index prepared and recorded. After the corner is destroyed, it should be reset once practical, and another corner recordation should be prepared and recorded documenting the newly set corner.

8.4.2 PLSS Corners

Contract documents also should specify if the contractor or MDT is responsible for resetting PLSS corners. All property controlling monuments (e.g., section corners and quarter corners) that will be disturbed by construction should be surveyed with references to support preparing and filing a pre-construction corner record. After construction, the property-controlling corner should be reset within 0.05-ft. of the previously surveyed position and a post-construction corner record showing the new monument should be prepared and filed.

8.5 New Right-of-Way Monumentation

New right-of-way monumentation is overseen by the district land surveyor. Right-of-way monuments are set at changes in the right-of-way width, at the beginning and end of projects, and at the points associated with the changes in geometry of the right-of-way baseline or other controlling horizontal alignment.

The right-of-way baseline may or may not be the same as the project design centerline.

Sections on right-of-way plans may show areas as “R/W=Existing.” These areas are not monumented.

8.5.1 Typical Methods

Right-of-way monuments should be set from project control using a total station or—in low multipath environments—GNSS. Points are set and then verified using an independent observation with an alternate control setup.

The as-staked horizontal position should be within 0.05-ft. of the designed coordinate position for both the setting of the point and the verification observation.

When using a total station, the verification observation may be made by moving the instrument to occupy a different control point or moving the backsight to a different control point.

When using GNSS, the verification observation should be made by moving the base station to a different control point.

8.5.2 Typical Materials

Typical materials for control are a 5/8-in. x minimum 24-in. rebar with 2-in. aluminum cap for soft surfaces and a brass plug for hard surfaces. Witness posts made of conduit or similar materials should be set at each point unless the post infringes on private property, falls on a hard surface, or otherwise conflicts with urban facilities. The witness post should be set 1-ft. inside the right-of-way monument (between the monument and centerline), and a decal should be applied to the post.

Reference monuments for the right-of-way, if set, should be 5/8-in. x minimum 24-in. rebar with a standard MDT red plastic cap. Reference monuments should be set 3-ft. inside the right-of-way monument on a line perpendicular to tangents or 90 degrees to a line tangent to curves.

8.6 Volumes

Volume surveys should use the methods stated in the MDT Standard Specifications under Measurement of Quantities. Quantities of excavations and embankments are measured for payment by a survey. Volumes are generally measured by the average end-area method or by a computer-generated surface-to-surface comparison between post-construction surface and existing ground.

8.7 Automated Machine Guidance

Once the proper equipment checks are performed and are within acceptable tolerances, coordinate with the Contractor, if possible, to synchronize grades with their AMG equipment. Complete this prior to starting work.

Use care where challenging construction areas and/or obstacles exist that could affect the GPS/GNSS sensor. Projects in high-multipath areas should not rely on GNSS sensors for AMG.

Check into control point(s) regularly to ensure accuracy and prevent errors. Regular equipment checks to known points are advised for construction activities or if machine control data are collected and used for as-built purposes.

Use of AMG in lieu of staking does not relieve the contractor from meeting the tolerances in contract documentation or Table 8.1. AMG must meet tolerances specified in contract documentation in same manner as projects constructed using traditional staking methods.

8.8 Staking Tolerances

Grade (elevation) checking of subgrade and/or crushed aggregate course (CAC) should be performed at an accuracy to meet the constructed tolerances in the MDT Standard Specifications for subgrade and aggregate surfacing.

In the absence of further guidance in the MDT Standard Specifications, MDT relies on the tolerances provided in Table 8.1. Tolerances represent the maximum variance that should be observed when stakes or grades are checked from project control by the EPM or their representative. Stakes and grades are checked using equal to—or higher—accuracy equipment than was used for the layout.

Exceptions to staking tolerances for special circumstances should be discussed in the construction survey scoping meeting. Unless otherwise noted, miscellaneous items not listed in Table 8.1 should be staked to a horizontal and vertical tolerance of 0.20-ft.

ITEM	HORIZONTAL	VERTICAL
Box Culverts	+/-0.10-ft.	+/-0.05-ft.
Bridge Substructures	+/-0.03-ft.	+/-0.03-ft.
Bridge Superstructures	+/-0.02-ft.	+/-0.02-ft.
Construction Centerline Control Points	+/-0.05-ft.	N/A
Construction Centerline Station Points	+/-0.10-ft.	N/A
Curbs, Sidewalks, and Bike Paths	+/-0.03-ft.	+/-0.02-ft.
Manholes, Inlets, and Culverts	+/-0.10-ft.	+/-0.03-ft.
Portland Cement Concrete Pavement	+/-0.10-ft.	+/-0.02-ft.
Slope Stake Locations	+/-2.00-ft.	+/-0.40-ft.
Traffic Markings	+/-0.20-ft.	N/A
Walls – Retaining, MSE, Sound, etc.	+/-0.10-ft.	+/-0.05-ft.
Wetland Mitigation Controls	+/-0.20-ft.	+/-0.20-ft.
Light and Signal Poles (incl. footings)	+/-0.20-ft.	+/-0.03-ft.
Stockpiles	N/A	+/-0.70-ft.
Dig outs / Quarries	N/A	+/-0.70-ft.
Topsoil	N/A	+/-0.70-ft.
Soft Shots	+/-0.30-ft.	+/-0.70-ft.
Hard Shots	+/-0.20-ft.	+/-0.30-ft.

Table 8.1: Construction Staking Tolerances

8.9 Construction Survey and Layout

8.9.1 Quality Control of Preliminary Surface

It is necessary to verify that the existing ground surface in Trimble Business Center (TBC) accurately represents the actual ground surface. Refer to the TBC Construction Process Documentation for the verification procedures.

8.9.2 Preliminary Staking

8.9.2.1 Clearing and Grubbing

Contract documentation provides different methods of measuring clearing and grubbing: a lump sum basis, an area basis, and areas to be included in the cost of other items. Staking should be compatible with the method of measurement.

Clearing lines on the insides of curves and at intersections should be given special attention to provide adequate site distance and clear zone visibility.

Stakes or lath should be spaced so that one lath can be seen from the next and not farther than 100-ft. apart in open and straight terrain. Frequency will depend on the terrain and density of foliage. Heavily timbered areas should be cleared in a somewhat irregular alignment to encourage a more natural appearing result. Stakes should be made as highly visible as possible, either with paint or flagging.

A limited number of trees and shrubs may be retained to blend the right-of-way with the adjacent terrain and enhance appearances; the construction surveyor should coordinate with the contractor to determine how saved trees or shrubs are marked. Trees or shrubs that are retained should be in good health and of a desirable species that will not create future maintenance problems.

8.9.2.2 Slope Staking

MDT and Contractors predominantly use 3D and AMG to model and build project earthwork, therefore stakes are not always needed to build roadway earthwork. Use Stakeless Slope Staking as much as possible to increase efficiency.

8.9.2.2.1 Stakeless Slope Staking

The term "catch" is defined as the point where the design roadway prism from the outermost hinge point intersects the ground surface. It is important to perform quality control of the design catch to ensure the accuracy of the ground surface used in the modeling software. Do this by comparing the design catch point to the surveyed catch point. The design catch point is acceptable if the tolerance is within 2.00 feet horizontally and 0.40 feet vertically. Perform these checks at maximum 200-foot intervals.

If model catch points are not within this tolerance, determine the extent of the area that is out of spec and collect new survey data. Update the ground surface in the modeling software. In addition to the quality control performed at the catch point there are additional quality control checks of the existing ground surface described elsewhere in this document that must be completed. This quality control ensures the accuracy of the ground surface for surface-to-surface quantity calculations for contractor payments. Refer to the guidance documents that describe these processes in detail.

Transfer the digital survey data to the Contractor as described in the Contract.

8.9.2.2.2 Conventional Slope Staking

The implementation of 3D modeling and AMG has mostly eliminated the need to determine the catch point and install slope stakes. Therefore, stakeless slope staking should be used unless there is a specific need to use conventional slope staking. A large percentage of slope stakes do not survive topsoil stripping. If stakes are placed, it is recommended to utilize reference stakes placed at or near the right-of-way. Since stationing along the project is commonly needed, it should be included on the stake. If the construction limits need to be identified, stake the catch point, and identify the stationing on the stake.

When conventional slope staking is used follow the steps defined below. It should be noted that the grade, slope, and distance to information included on the slope stake is rarely used anymore and, in most cases, can be eliminated. The catch point should be surveyed at all major terrain breaks, changes in the typical section, culvert locations, and at each cross section provided in the plans.

If stakes are necessary, install stakes that slope away from centerline approximately 30 degrees from perpendicular. Mark the front with cut/fill information. Mark the back with station identification. Use two stakes if necessary.

8.9.2.2.3 Slope Stake Markings

Fill stakes should be marked with the fill to the outer fill hinge point, the distance to centerline, and the slope of the fill.

Cut slopes should be marked with the cut to the outer ditch hinge point, the distance to centerline, and the slope of the cut.

Reference stakes should be set outside the slope stake, marked with the offset to the stake it is referencing, the cut/fill to the hinge point, and the distance to centerline.

Shallow cuts and transitions from cut to fill can be marked with DL for daylight stakes.

See Section 8.10 Slope Stake Diagrams.

8.9.3 Road Approaches and Small Dikes

Road approaches and small dikes should be staked as a separate alignment at a sufficient frequency to construct the designed horizontal and vertical geometry.

8.9.4 Borrow Pits

Borrow areas must be surveyed with global navigation satellite system (GNSS) or a total station prior to excavation.

8.9.5 Grade Connections to Existing

Where the roadway grade meets an existing bridge or road, exercise care to provide a smooth transition between design and existing elevations. Verify that elevations shown for existing features reasonably match the actual elevations shown at all tie-in points.

8.9.6 Bridge Survey

Construction survey and layout on structures should be completed in accordance with contract documentation. The survey work elements require precision not generally practiced on most other highway construction projects. Errors in details like span lengths, column lengths, or cap elevations can cause costly rework and can significantly delay the project.

Therefore, when performing layout, staking, or checking the Contractor's work use survey equipment that is equal to—or higher—accuracy than the tolerances for bridges described in the contract documents. Checks such as assessing the alignment of features or taping between staked features should be performed throughout the layout process.

GPS instruments do not generally meet the tolerances for checking grade. Use a level for checking grade.

8.9.6.1 Bridge Control

Control should be in place and verified prior to layout out of any bridge features. New control should be established in conformance with Chapter 4: Control Surveys.

8.9.6.2 Bridge Construction Review

Review of bridge layout should include but is not limited to:

- Checking dimensions on bridge plans prior to staking. Check elevations shown on the plans from finished grade down through the deck slab, girder, shoes, crossbeams, columns, and footings. Check span lengths, skew angles, and horizontal control of bridge alignment.
- Review road or other plans for items such as special embankments that may affect layout of references for the structure.
- Check the alignment and stationing of roadway alignment as staked in the field.

Bridge plans are designed and produced using a combination of grid and ground dimensions. Stations shown on bridge plans are state plane grid stations based on state plane coordinates. Dimensions shown on the bridge plans are horizontal ground distances and are not state plane grid distances. The bridge plans should indicate horizontal datum, vertical datum, and the project’s combination scale factor (CSF).

8.9.7 Storm Drain

8.9.7.1 Culverts

Survey culvert(s) in accordance with the Contract. Stake pipes to fit the drainage and roadway slopes. Adjust the pipe location as needed to fit these field conditions. It can be useful to stake the culvert in unison with the adjacent fill slopes to verify the length of pipe fits the slope. Taking cross sections and profiles can help fit the pipe to the field conditions. Determine the culvert lengths and submit them with the culvert survey notes to the Project Manager. The Project Manager’s approval of the survey is required before culverts can be ordered.

Culverts are staked at end of pipe (EP) and with hubs set at offsets in line with the centerline of pipe at an offset distance beyond construction limits. A guard stake over each hub should show the cut or fill to the flow line and the distance offset from the hub to the end of the culvert. Other information relative to the length, size, and type of pipe may be shown on guard stakes or with a lath.

After a pipe is staked, a check should be made of the total fall and direction of flow. Culverts without elevations specified in the plans should be staked and installed with a minimum gradient of 0.3% for reinforced concrete pipes (RCPs) and 0.5% for corrugated metal pipes (CMPs). If invert elevations are not specified, the culvert invert should be staked with approximately 10% of the pipe below the flow line elevation of the inlet and outlet channels to minimize piping, obtain a more solid bedding, and provide opening for small flows.

8.9.7.2 Concrete Box Culverts

The construction surveyor should review and check plans and shop drawings prior to stakeout of concrete box culverts. Reference lines should be set parallel to the centerline of the structure or at an offset to the edge of the culvert. The reference lines are set at the discretion of the EPM and may be used to set alignment and to install screed rails. Offset reference hubs should be set outside the construction area at the projection of the structure centerline or at a projection of other reference lines.

8.9.7.3 Dikes and Ditch Blocks

Dikes should be staked around the dike perimeter with an adequate number of stakes to delineate the features of the dikes and to allow an accurate computation of volumes.

Ditch blocks should be staked at the shoulder with a stake showing stationing of the ditch block with its height, length, and side slopes.

8.9.7.4 Inlets

Inlets should be staked with a stake, hub, or other marker at the center of the structure and with two or more reference offsets to establish the structure centerline.

8.9.7.5 Curb, Gutter, and Sidewalks

Curbs should be staked with a parallel reference line behind the curb at a constant offset distance with hubs and tacks. The EPM should confirm offset distances with the contractor prior to running the reference line. Offset distances and cut/fills should be marked to the back of curb. An adequate number of stakes should be used to ensure proper grade and alignment, including horizontal and vertical controlling points. Where practical, the radius points of curves should be staked.

Sidewalks typically are constructed using the relationship shown on the plans between the sidewalk and back of curb and thusly are usually not staked.

8.9.8 Miscellaneous Items

8.9.8.1 Fences

The construction survey crew should confirm they have the latest right-of-way plans and agreements at the time fences are staked. An adequate number of stakes should be set at reasonable spacing to allow for fence construction without extensive use of surveying equipment. In areas where “right-of-way equals existing” on the plans, the right-of-way location is only approximate. If the exact location of the right-of-way is critical, a retracement survey of the existing right-of-way is required.

8.9.8.2 Bin and Retaining Walls

Bin and retaining walls should be staked with offsets outside the construction zone with the cut or fill shown to the bottom of bin or retaining wall.

8.9.8.3 Signs

Stake signs in accordance with the Contract. Adjust sign locations to fit existing field conditions. Once the location has been determined stake the sign location with a lath, stake, or hub, and include the pertinent identifying information. Collect the necessary grade shots on the roadway shoulder and ground shots at the post location to calculate the signpost length. Submit the survey information to the Project Manager. The Project Manager will review the survey notes and once approved the sign posts can be ordered.

8.9.8.4 Pavement Markings

Pavement markings should be staked at the locations shown on the plans and under the direction of the EPM. Pavement markings should be staked in accordance with the contract documents.

8.9.8.5 Utility Relocations

Relocated utilities require staking to provide alignment and grade and to provide minimum horizontal or vertical clearances. Carefully review the proposed roadway construction to confirm adequate clearances are provided and that the relocated utility does not conflict with the operation of other facilities.

8.9.8.6 Guardrails

Installation instructions for guardrails are shown in contract documents. Adjustments may be necessary but should be approved by the appropriate authority. The method used for staking guardrail will be determined by the EPM and explained to the project inspector and contractor.

8.9.8.7 Comfort Stations

Comfort stations require staking building locations and such items as drain fields, underground sprinkling systems, driveways, sidewalks, and locations for planting trees and shrubs.

A careful review of the plans for the building site and attendant facilities should be made before staking is begun. Baselines or reference lines should be established at the proper locations and their control points referenced to prevent destruction. Line and grade shall be set for the footings of the building, for sewer facilities, and to provide a convenient reference for workers to establish batter boards and lay out the facilities.

8.10 Slope Stake Diagrams

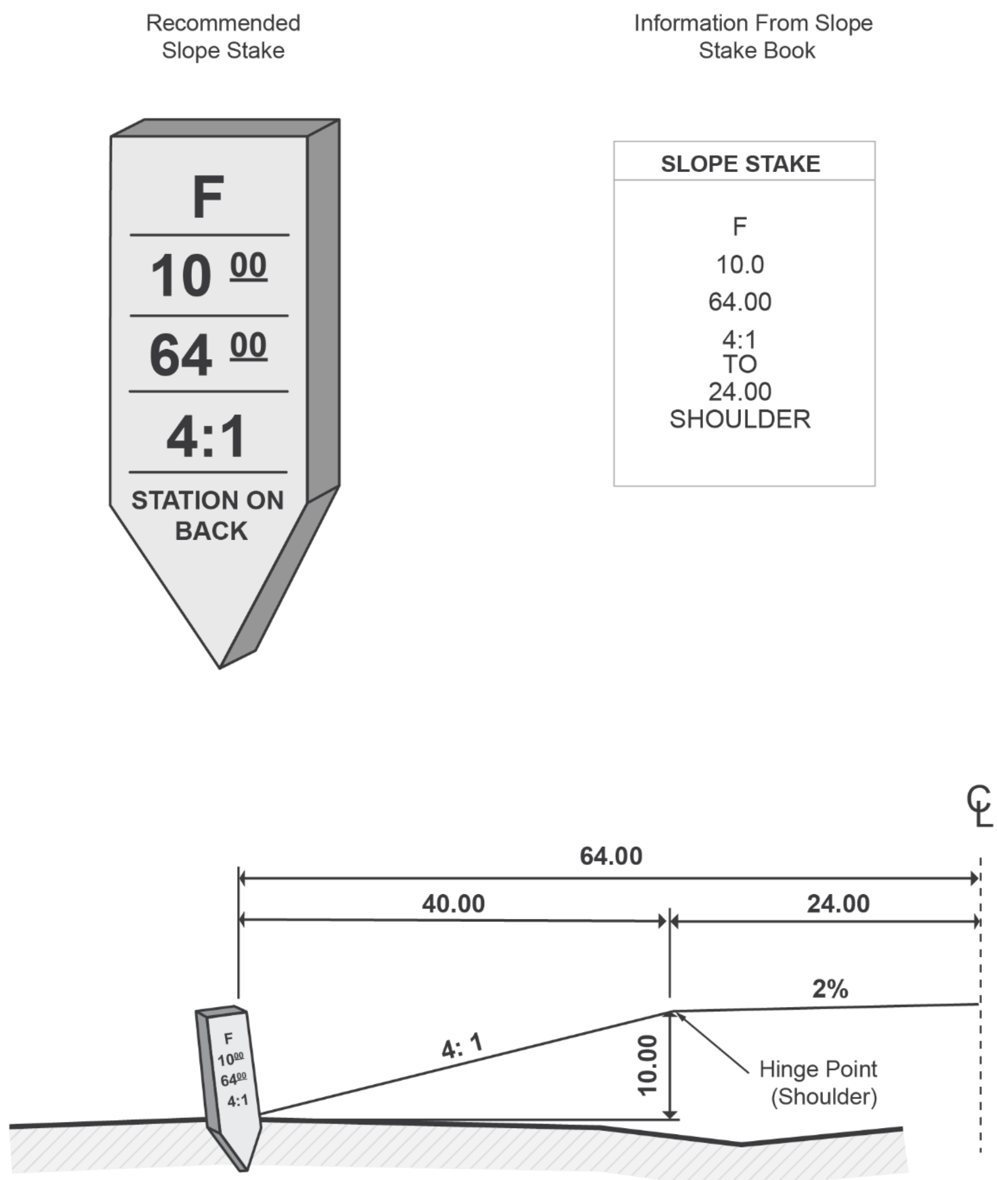


Figure 8-2: Slope stake for normal fill section

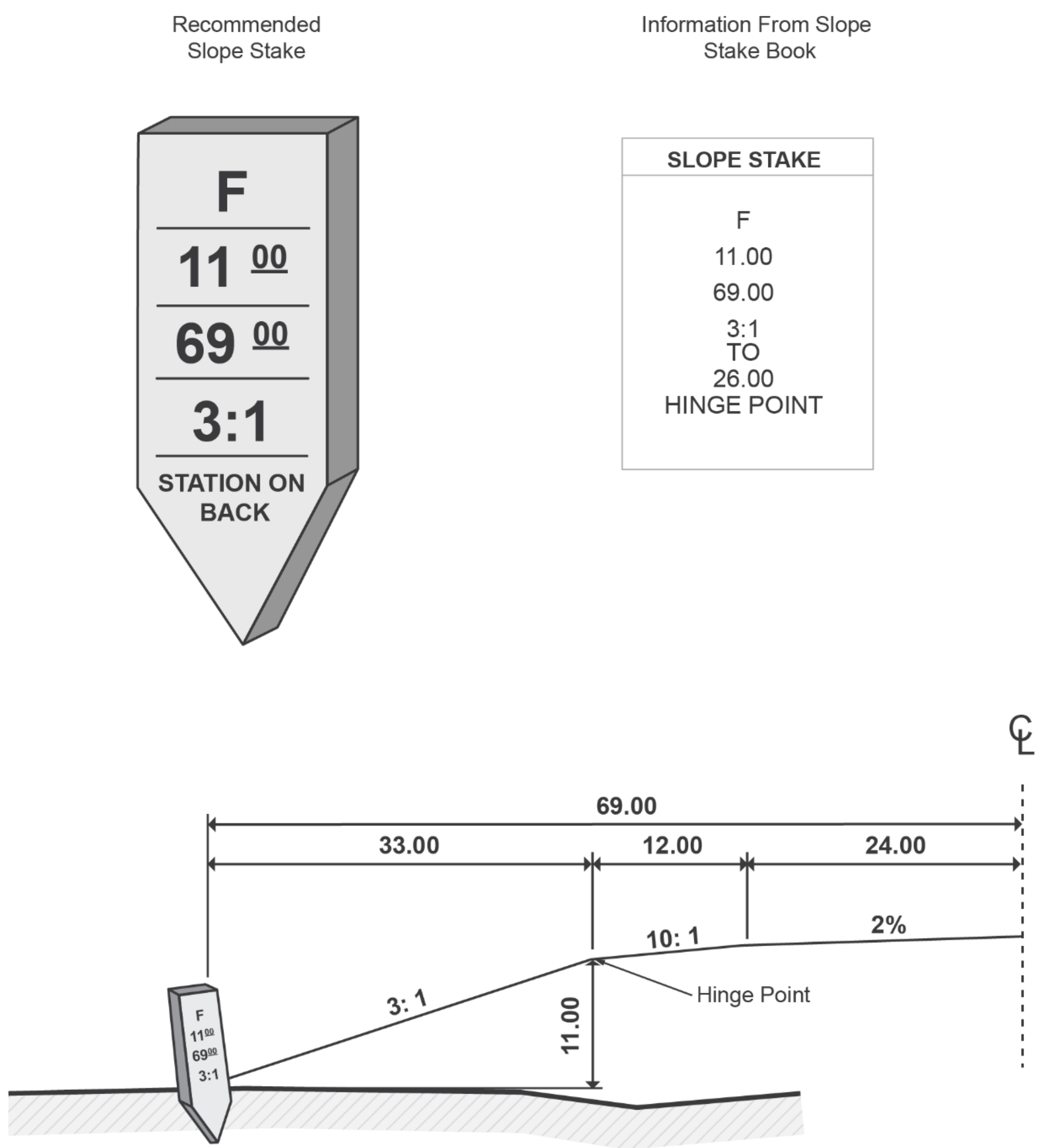


Figure 8-3: Slope stake for fill section with safety shoulder

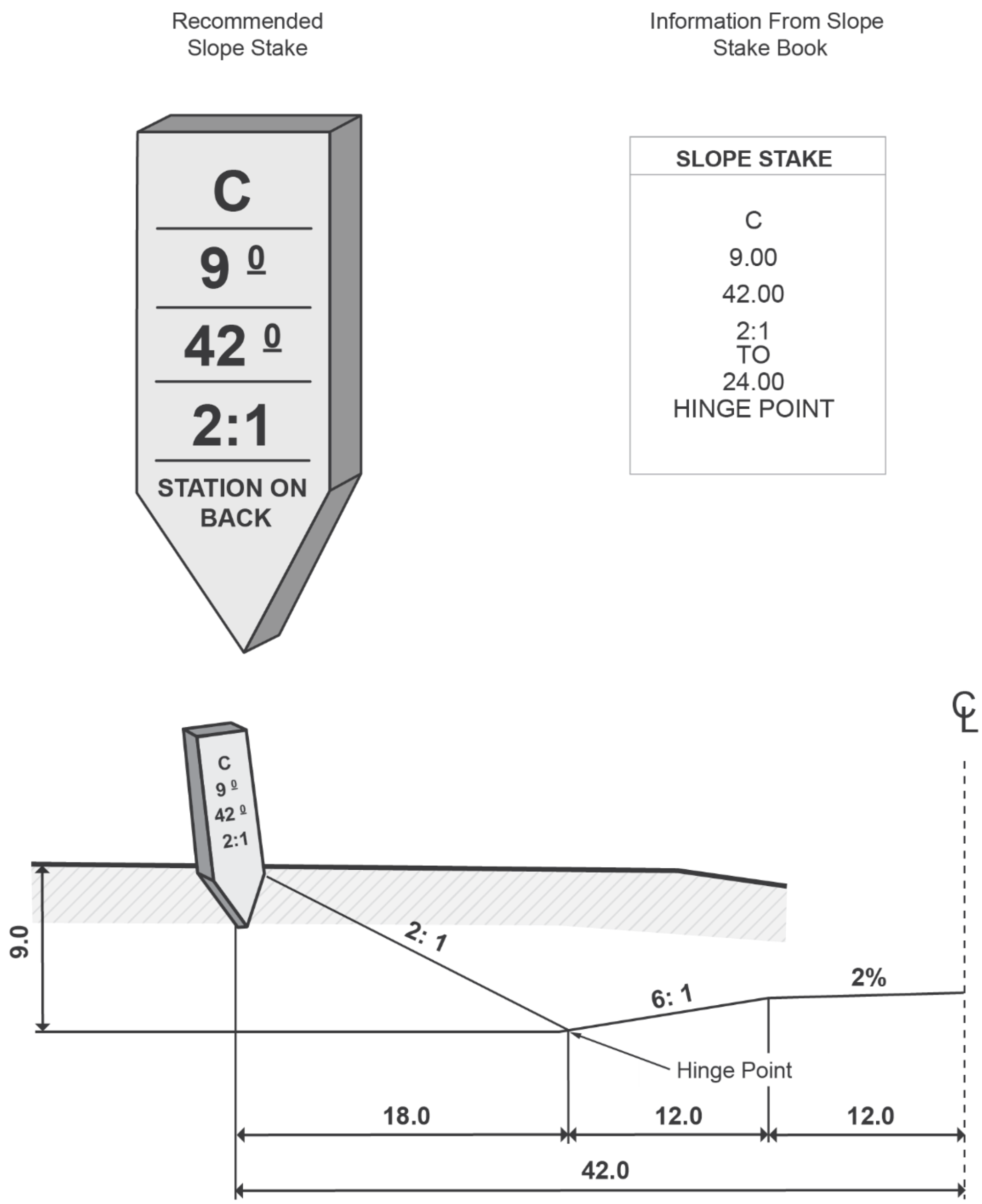


Figure 8-4: Slope stake for cut section with v-ditch

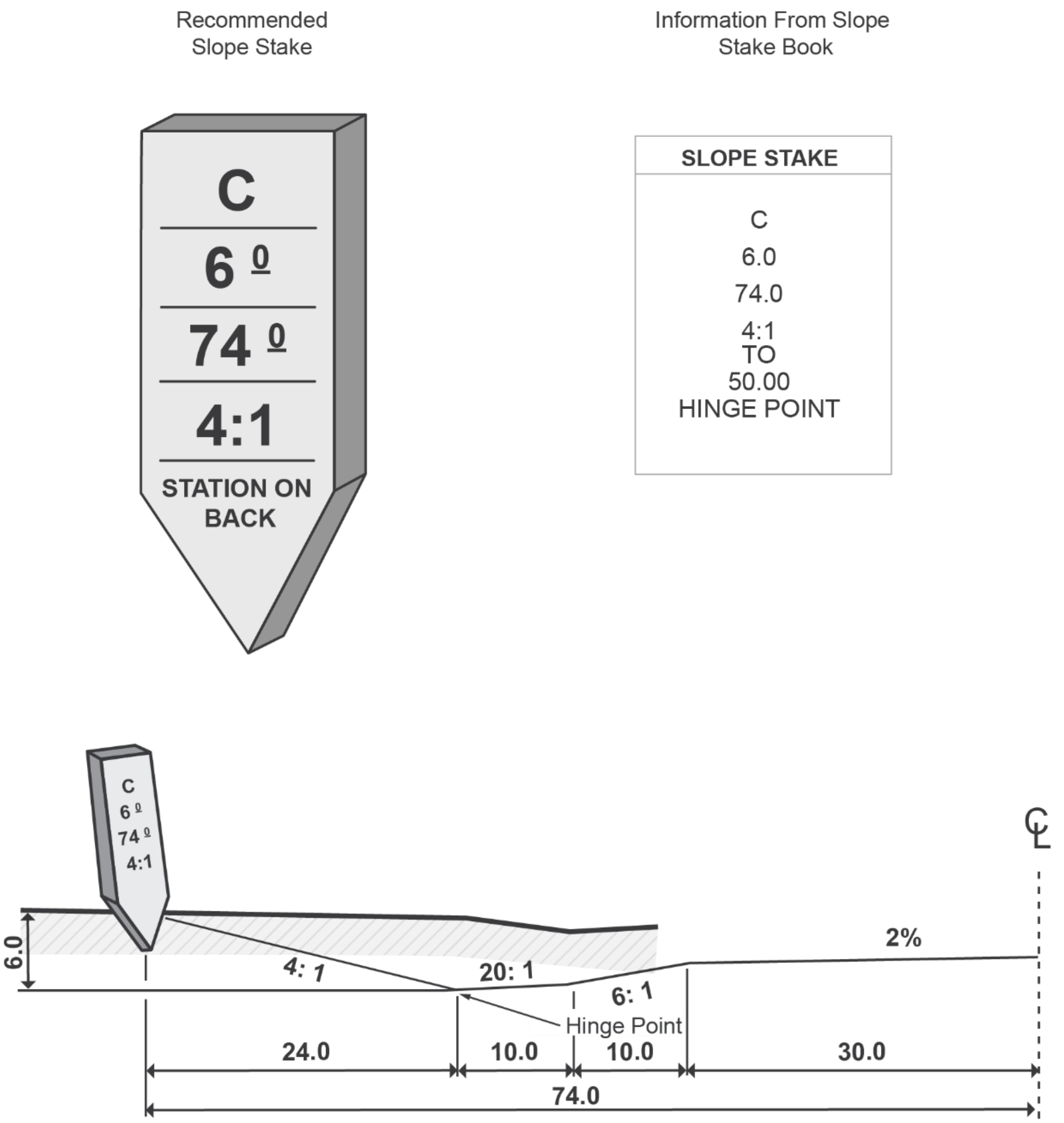


Figure 8-5: Slope stake for cut section - flat-bottom ditch

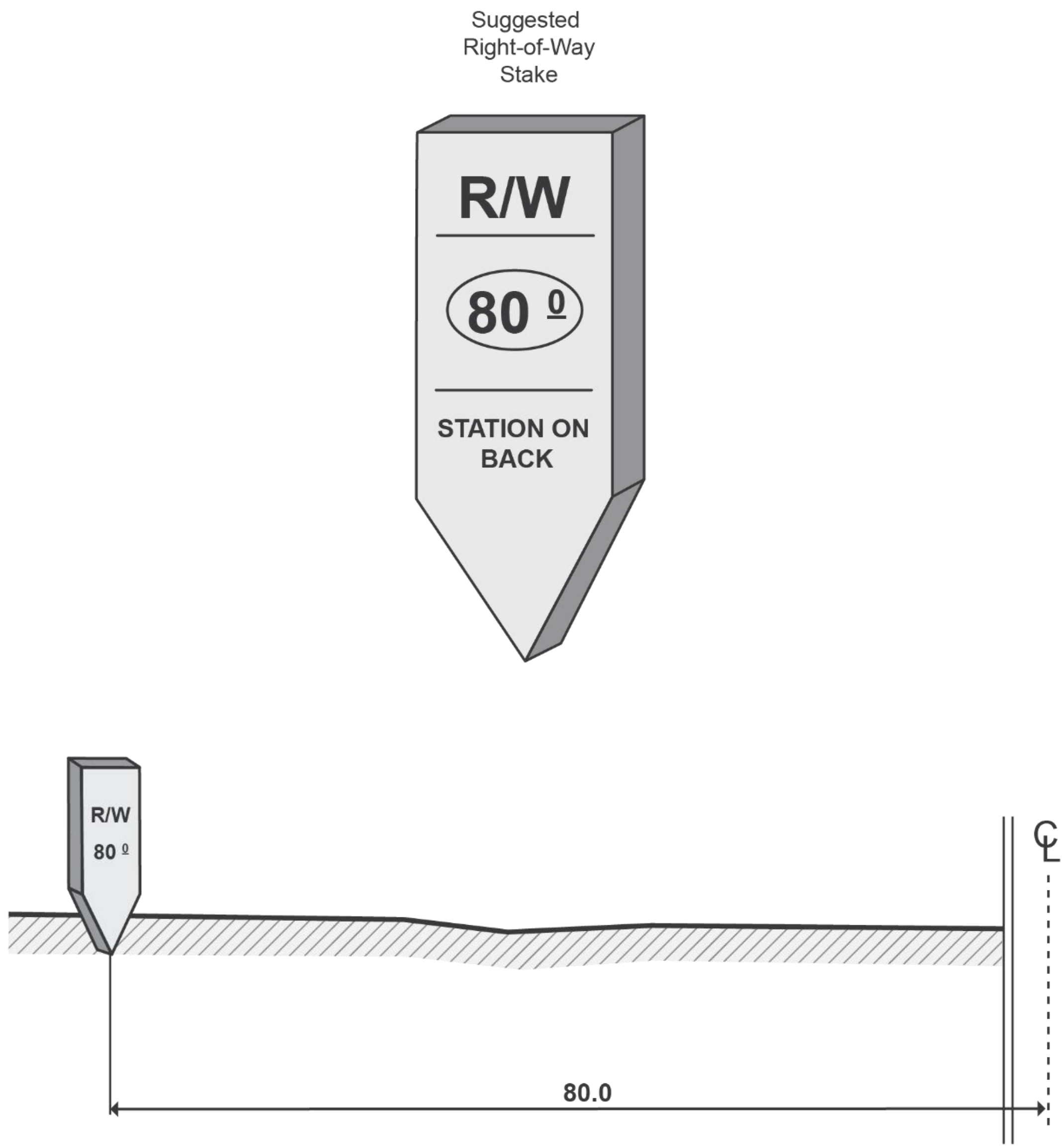


Figure 8-6: Suggested right-of-way stake

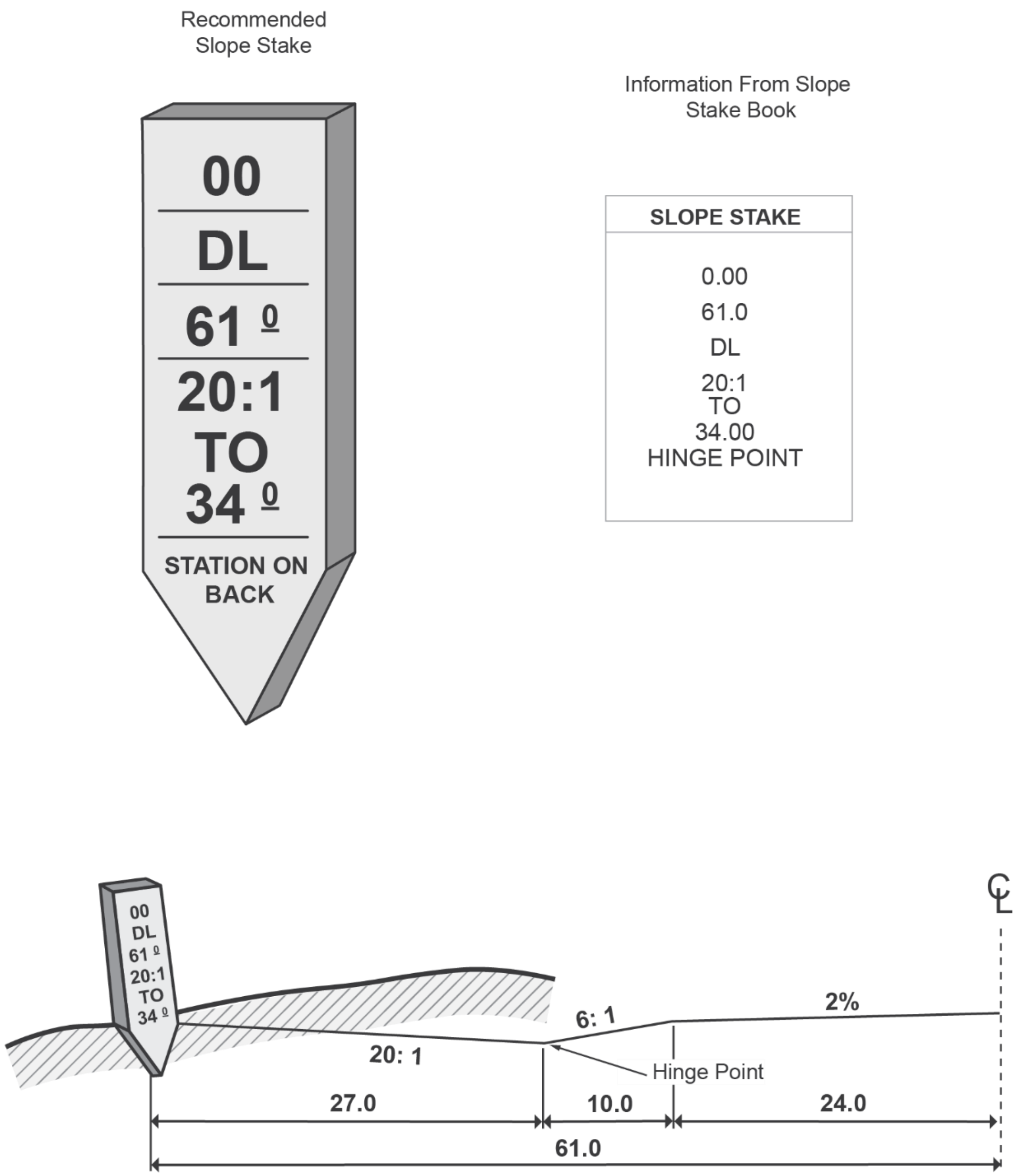


Figure 8-7: Slope stake for daylight section

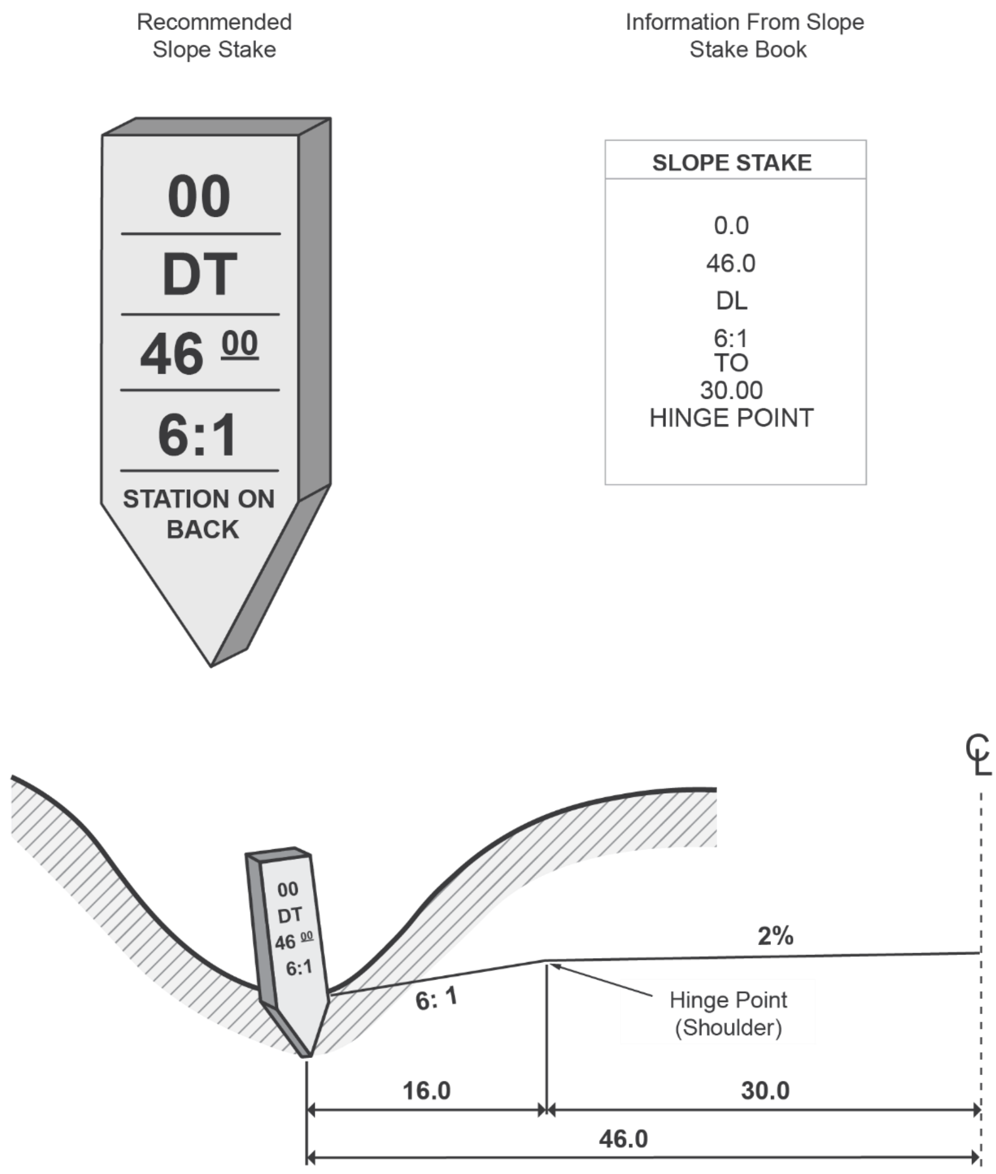
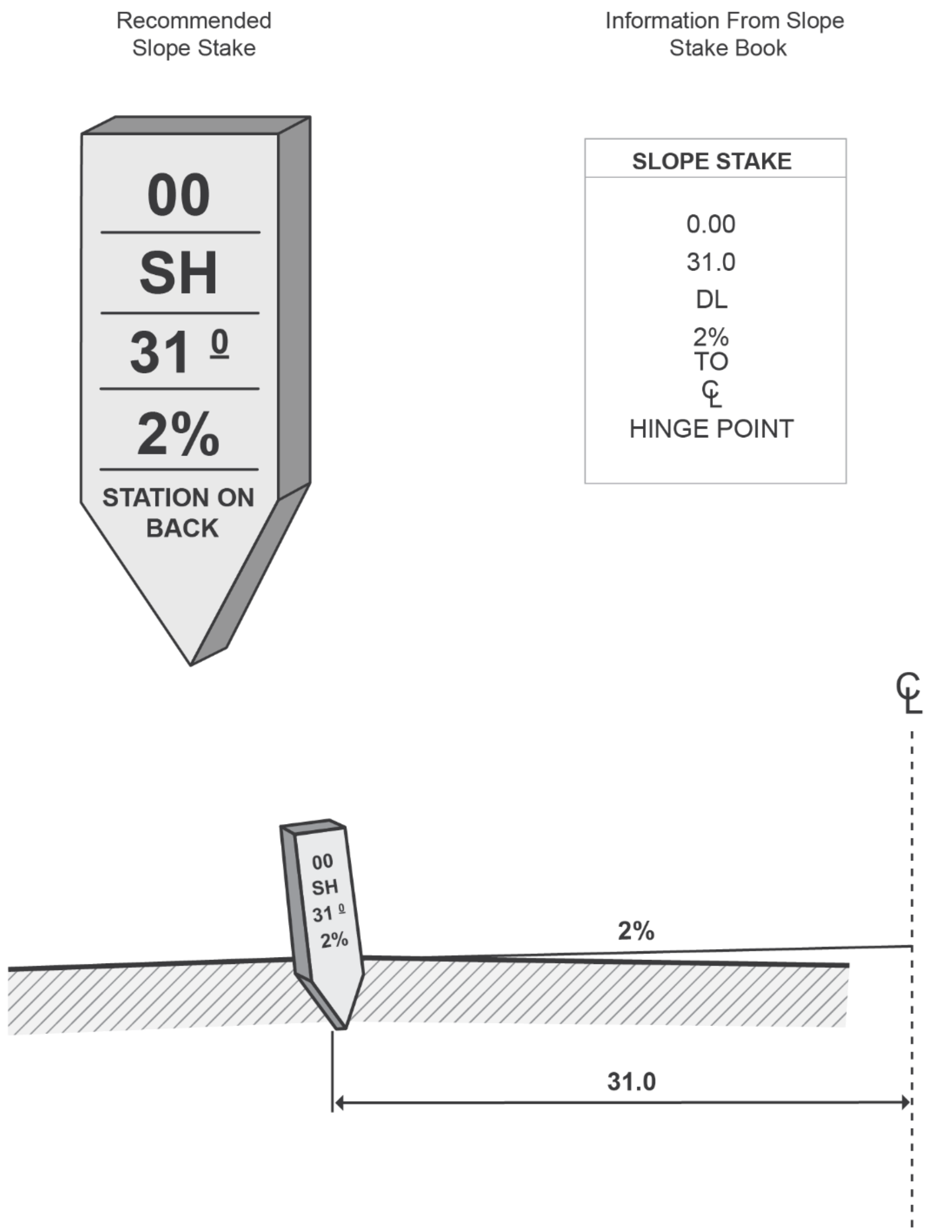


Figure 8-8: Slope stake for 00-ditch section

Figure 8-9: Slope stake for 00-shoulder section



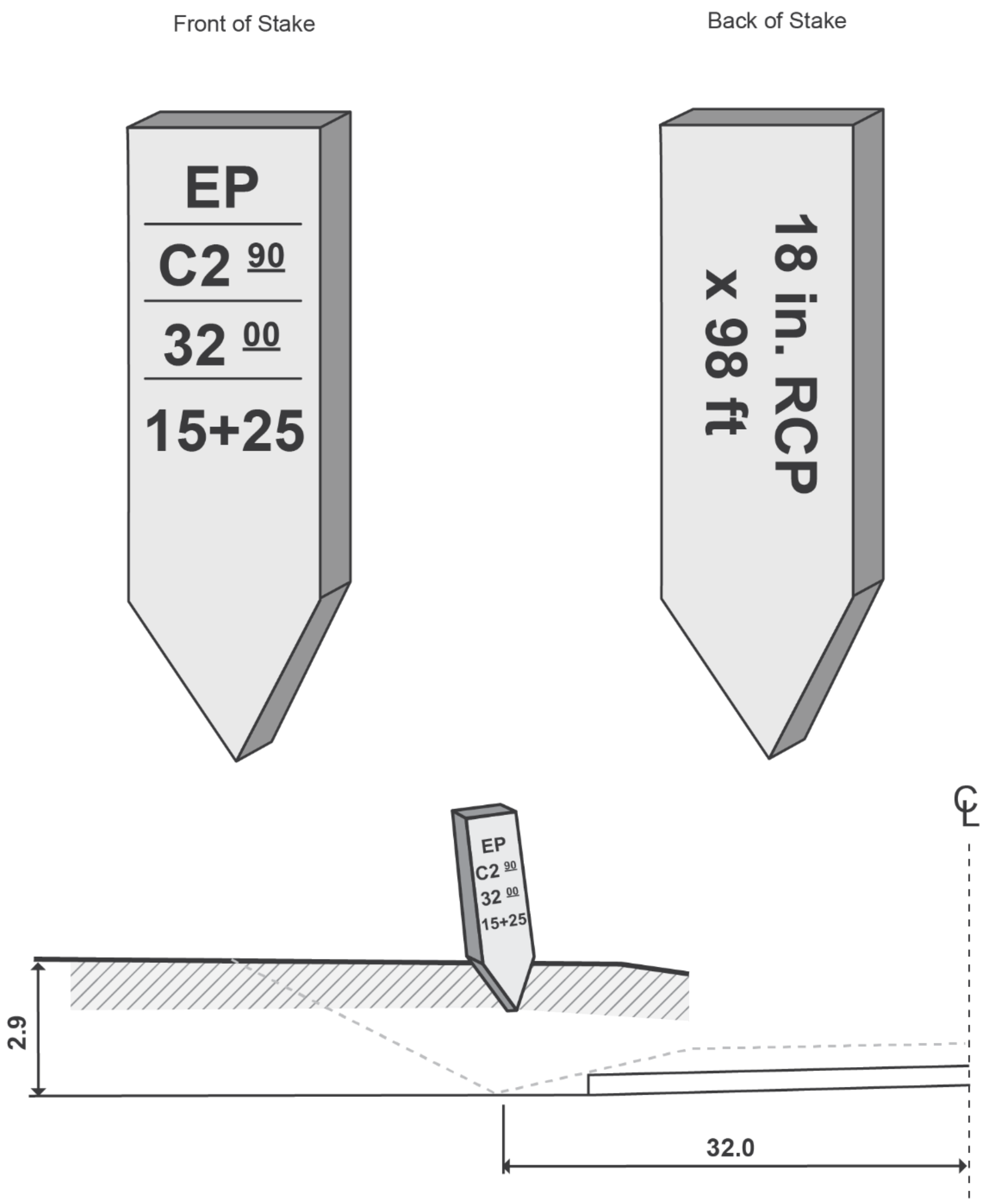


Figure 8-10: Slope stake for normal culvert section

APPENDIX A

GLOSSARY

APPENDIX B

TRIANGLES

APPENDIX C

CURVES