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Chapter 18
MISCELLANEOUS FOUNDATIONS

18.1 GENERAL

18.1.1 Overview

This Chapter provides guidance on the design of foundations for miscellaneous structures, including:

- lightly-loaded buildings that might be used for rest areas or MDT maintenance facilities;
- culverts and drainage pipes;
- various types of traffic structures (e.g., luminaires, sign bridges, traffic signals); and
- sound walls.

These types of facilities can involve the use of shallow and deep foundations, as well as retaining walls. Therefore, the project geotechnical specialist should also review the foundation design methods provided in Chapter 16 for bridge foundations and Chapter 17 for earth-retaining structures.

18.1.2 Responsibilities

The following identifies the necessary coordination between the Bridge Bureau, Hydraulics Section, Traffic Engineering Section and the Geotechnical Section:

1. Traffic Structures. Foundation designs of overhead sign bridges, cantilevered sign supports, cantilevered traffic signal supports, luminaires, etc., involve a joint effort between the Bridge Bureau, Traffic Engineering Section and the Geotechnical Section. The Traffic Engineering Section selects and designs the signs, traffic signals, luminaires, etc., and estimates the loads (e.g., wind) that will be imposed on the structure. The Bridge Bureau determines the structural design required to meet the loading demands. The Geotechnical Section determines the foundation requirements for the structure.

2. Hydraulic Structures. For culverts, drainage pipes, vaults and detention structures, the Hydraulics Section will determine the hydraulic requirements (e.g., type, size, depth) for the culvert or pipe and the size of the vault or detention basin. The Geotechnical Section will characterize local site conditions and foundation support capabilities, while the Bridge Bureau provides structural design of any non-standard structures.

On some projects, the contractor will be responsible for design of any miscellaneous structures. In these cases, the following information should be provided in the contract documents:

- any available boring logs and other site data;
- required vertical and lateral clearances;
- dimensions, grades and elevation;

- product information; and
- design criteria (e.g., wind, water, traffic and seismic loads).

The Geotechnical Section will be responsible for providing any available boring logs. When no boring information is available, the contractor will be responsible for making the borings necessary to obtain soil data to design the foundation. Procedures for performing explorations should be in accordance with the general procedures discussed in Chapter 8. The contractor will be responsible for performing the structural and foundation design and submitting the design calculations and shop drawings to the Project Manager. The Project Manager will forward this information to the responsible MDT unit (e.g., Geotechnical, Hydraulic, Bridge) for review and approval.

18.1.3 References

For further guidance on the design of miscellaneous foundations, consider the following references in addition to those listed in Chapter 16 and Chapter 17:

1. *AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, 2001;
2. *AASHTO Guide Specifications for Structural Design of Sound Barriers*, 1989 (with 2002 interim);
3. Hu, Z., McVay, M., Bloomquist, D. Herrera, R., and P. Lai, "Influence of Torque on Lateral Capacity of Drilled Shafts in Sand," *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 132, No. 4, pp.456-465, 2006;
4. NAVFAC *DM-7 Foundations and Earth Structures*, Department of the Navy, Naval Facilities Engineering Command, May 1982;
5. NCHRP 473 *Recommended Specifications for Large-Span Culverts*, National Research Council, TRB; and
6. Peck, R.B., Hanson, W.E. and T.H. Thornburn, *Foundation Engineering*, Wiley, 1974.

18.2 MISCELLANEOUS FOUNDATION DESIGNS

18.2.1 Buildings

Small buildings typically include single story structures (e.g., storage facilities, maintenance buildings, rest area structures). Typically, these buildings are supported on shallow spread footings or on pile or shaft foundations where soft compressible soils are present.

18.2.1.1 Design Procedures

Geotechnical design analyses for building foundations include bearing capacity, settlement and, in some cases, lateral load capacity. Guidelines provided in the *International Building Code* (IBC, 2006) should be followed for general building foundation design guidance. The IBC currently specifies that all foundations be designed using an allowable stress design methodology.

General guidance for assessing building foundation capacity is to use the design equations presented in the *AASHTO LRFD Specifications* or foundation engineering textbooks for Allowable Stress Design. A bearing capacity factor of safety of 3 is normally used for spread footing design and required factors of safety (or resistance factors for LRFD) for deep foundations are provided in Chapter 16. Do not use the charts in IBC (2006) showing presumptive allowable foundation bearing pressures, lateral bearing and lateral sliding coefficients.

18.2.1.2 Settlement

Buildings supported by spread footings must be checked for settlement. Charts and equations provided in most foundation textbooks can be used for checking settlement of spread footings founded in cohesionless soils.

Evaluate the settlement of buildings located on cohesive soils using conventional consolidation settlement equations. It is necessary to determine both the magnitude and rate of settlement.

18.2.1.3 Seismic Loading

The potential for seismic loading should be considered in accordance with the IBC requirements. In the IBC, the level of ground shaking is based on a seismic event with a 2% probability of occurrence in 50 years, resulting in an average return period of 2500 years. IBC refers to this ground motion as the Maximum Considered Earthquake (MCE). The resulting ground motion is multiplied by a factor of 2/3rds to define the design ground motion. This design ground motion (i.e., with the 2/3rds factor) will usually be greater than the basis for design in the *AASHTO Specifications*. IBC requires the design ground motions based on the 2500-year earthquake to be used for evaluating geotechnical response to seismic loading (e.g., liquefaction and lateral earth pressures), as well as building response. If liquefaction or other types of ground failure are predicted, it may be necessary to mitigate the potential for liquefaction through the use of structural systems or ground improvement. See Chapter 19 for further discussion of these topics. The decision on whether to mitigate unacceptable conditions will depend on numerous factors and should be discussed with the project design engineer.

18.2.2 Culverts and Drainage Pipes

Culverts and drainage pipes are used on MDT projects to convey water away from roadways and to route creeks, streams and similar water flows under or around embankments. The pipes can be concrete, steel, aluminum or thermoplastic (e.g., polyethylene (PE) or polyvinyl chloride (PVC)). Concrete box culverts can also be used. Culvert pipes are either flexible or rigid, depending on the rigidity of the pipe material. Corrugated metal pipe (CMP) and thermoplastic pipe are common examples of flexible pipe; precast concrete is a typical rigid pipe.

18.2.2.1 Design Procedures

The Hydraulics Section is responsible for selecting the size and pipe type based on soil and hydraulic considerations. Generally, the Hydraulics Section follows the guidance provided in Sections 3 and 12 of the *AASHTO LRFD Bridge Design Specifications*. The *AASHTO LRFD Specifications* require that the backfill around the pipe conform to a minimum soil class dependent upon pipe type. MDT may have more stringent requirements for certain pipe sizes or when poor soil conditions are present. Sections 26 and 27 of the *AASHTO LRFD Bridge Construction Specifications* provide compaction criteria for soil backfill around flexible and rigid culverts, respectively. Additional background used by the Hydraulics Section for typical culvert pipe design is given in Chapter 17 of the *MDT Roadway Design Manual*. Typical designs are provided in the *MDT Detailed Drawings*.

The following design situations summarize the typical types of support that the Hydraulics Section may request from the Geotechnical Section during the design of culvert pipes:

1. Case 1 — Open Excavation. Open excavation techniques are used to remove and replace an existing culvert because of performance problems (e.g., leaking, partial collapse, undersized). The excavation is typically backfilled with the excavated material. Generally, only minimum geotechnical design effort is needed. Settlement and bearing issues for the new culvert should not be significant, because no new load is being placed on the soil below the culvert. However, the Hydraulics Section may request input from the project geotechnical specialist on soil conditions in the fill and the foundation soils below the culvert to assess constructability issues (e.g., excavation slopes, shoring design). The presence of boulders in the fill or below the fill, depending on the shoring type anticipated, would also be of interest.

2. Case 2 — Extending Existing Culvert/New Construction. For this case, differential and total settlement along the culvert within the new fill must be evaluated in addition to the issues identified for open excavation (Case 1). See Chapter 15 for the estimation of settlement of the new fill over the extended culvert. Checks may also be necessary for bearing stability and general constructability if soft soils are present. When excessive settlements are predicted, recommendations to mitigate the settlement are generally required.

The design procedures given in Chapter 16 can be used if ground conditions are such that the culvert pipe must be supported by deep foundations. Typically, the use of deep foundations to support culvert pipe only occurs where soils are very compressible. If deep foundations are used, one of the key steps in the design process is the estimation of design loads on the culvert pipe. These loads will depend on the type of trench conditions. The procedures in the *AASHTO Specifications* and in DM-7 can be used to estimate these loads.

18.2.2.2 Seismic Loading

Typically, culverts and drainage pipes are not designed for seismic loading and the current *AASHTO Specifications* provides no guidance in this area. For critical culverts or drainage structures, which could imperil a roadway or bridge if they were to fail during a seismic event, the project geotechnical specialist may need to consider the potential for seismic loading. Guidance for the seismic design of culverts and drainage pipes is provided in NCHRP 12-70 *Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes and Embankments* (2008) and in the FHWA/MCEER *Seismic Retrofitting Manual for Highway Structures: Part 2 – Retaining Structures, Slopes, Tunnels, Culverts and Roadways* (2008).

18.2.3 Overhead Signs, Highway Luminaires and Traffic Signals

18.2.3.1 Foundations

The Traffic Engineering Section has Detailed Drawings showing typical foundation designs for luminaries and some types of traffic signals; see the *MDT Traffic Engineering Manual*. No specific description exists to define applicable soil conditions for use of these typical foundation designs; however, generally, these conditions involve medium dense to dense granular soil. Where subsurface conditions are less favorable (i.e., very loose to loose cohesionless or very soft to medium stiff cohesive soil, groundwater is present, etc.) or if nonstandard loadings are applied, a special foundation design may be required.

Most of MDT's traffic structures are founded on drilled shafts. Occasionally, spread footings or driven piles may be used where conditions warrant these alternative foundation types. The design of foundations for traffic structures involves the same foundation design checks as for bridge foundations (i.e., axial capacity and lateral resistance) summarized in Chapter 16. For single pole luminaires and mast arms, the torsional response must also be considered. Unless agreed to otherwise by the Geotechnical Engineer or Geotechnical Operations Manager, a geotechnical exploration should be conducted near each traffic structure location if the structure is greater than 20 ft (6 m) in height.

The primary difference relative to other foundations is that most traffic structures will have a large moment and a relatively small vertical load. Consider the following during the design:

1. Drilled Shaft Foundations. The length of the traffic structure foundation is normally short compared to a bridge foundation. The short length relative to the stiffness results in the shaft behaving as a rigid system with the capacity limited by soil strength. Most bridge foundations behave as a flexible system where the flexural capacity of the shaft limits the applied load. Typically, the response of a shaft with a length to diameter (L/D) ratio

of 3 will be determined by soil failure, whereas a shaft with an L/D ≥ 7 will be controlled by flexure or moment capacity of the shaft. This difference in controlling behavior must be considered in the analysis method. Although the same concept occurs for driven pile foundations, the small diameter relative to the length for typical driven piles results in use of a group of driven piles and a pile cap to meet moment demands.

2. Spread Footings. The large overturning moment relative to the vertical load results in large load eccentricities. The eccentricity reduces the effective width, often resulting in a spread footing that appears to be too large for the loads. For this reason, the spread footing is not usually considered a very efficient foundation for traffic structures.

18.2.3.2 Design Methods

The foundations for overhead signs, luminaires and traffic signals have been typically selected on the basis of requirements in the *MDT Traffic Engineering Manual*. For sites where a special design is required because of unsuitable soil conditions or non-standard design, special designs are generally prepared by a consultant. In these situations, the Geotechnical Specialist may be requested to review the design submittals or perform independent checks on the consultant's foundation design. There may also be cases where the Geotechnical Section assumes responsibility for the foundation design of overhead signs, luminaires and traffic signals.

Following are two design methods that can be applied to the lateral design of traffic structure foundations:

1. Broms' Equations. Broms' equations are summarized in two ASCE papers, "Lateral Resistance of Piles in Cohesionless Soils," *Journal of Soil Mechanics and Foundation Engineering,* May 1964, and "Lateral Resistance of Piles in Cohesive Soils," *Journal of Soil Mechanics and Foundation Engineering*, March 1964. Section 13 of the 2001 *AASHTO Standard Specifications for Structural Support for Highway Signs, Luminaires, and Traffic Signals* also provides a discussion of the Broms' method relative to sign foundation design. This approach allows determination of the embedment length for specified moment, shear and soil properties. Results of studies by Hu et al. (2006) show that the Broms' method tends to over predict the lateral capacity of short shafts (no torque) but better predicts deeper shaft response.

2. Computer Program. This procedure involves the use of a computer program (e.g., LPILE) to determine lateral design. LPILE is described in Chapter 13. The use of LPILE is summarized in Chapter 16 for the lateral loading to bridge foundations.

Both the simplified Broms' method and LPILE approach are suitable for traffic structures that do not involve significant amounts of torsion. For single cantilever and mast arms, a significant amount of torsion occurs during wind loading. Normal practice is to treat torsional and lateral loading separately using one of the two methods identified above for lateral loading and a Columbic friction model (normal stress times the coefficient of friction) or an axial friction model (rotated 90°) for torsion. "Influence of Torque on Lateral Capacity of Drilled Shafts in Sand" (Hu et al, 2006) shows that the torsional resistance can be predicted in sands within 20% using the vertical effective overburden stress times β from the FHWA *Drilled Shaft Manual*, except for short shafts (L/D = 3).

The consequence of the torsional component to loading is that the lateral capacity of the foundation is reduced. The Florida DOT sponsored research at the University of Florida to evaluate the coupled lateral/torsional load mechanism; see the report "Determine Optimum Depths of Drilled Shafts Subject to Combined Torsion and Lateral Loads Using Centrifuge" submitted to Richard Long and Peter Lai at Florida DOT, April 2003. This information is summarized in the "Influence of Torque on Lateral Capacity of Drilled Shafts in Sand" (Hu et al, 2006). Results of these studies suggest that the reduction in lateral capacity in dry sand can be up to 50% for torque to lateral load ratios of 6 (ratio in meters). In saturated sands, both the change in vertical effective stress and the use of drilling fluids can affect the torsional capacity. Simplified methods of combining the P-y approach in LPILE with the results of the centrifuge study are provided in "Influence of Torque on Lateral Capacity of Drilled Shafts in Sand" (Hu et al, 2006).

18.2.3.3 Seismic Loading

Typically, highway luminaires and traffic signals are not designed for seismic loading. However, the affects of seismic loading may be relevant if these traffic structures are located in soils that are expected to liquefy during the design seismic event. In this case, the project geotechnical specialist should report the risk of liquefaction to the Project Manager. An informed decision should be made considering the tradeoffs between accepting the risk and mitigating the potential for liquefaction by using deeper foundations or ground improvement methods.

18.2.3.4 Miscellaneous Design Considerations

A number of other practical issues need to be considered during the geotechnical design of traffic structure foundations, as summarized below:

- The vertical loads from signs, signals and luminaires are very low and usually do not control design. However, if several feet (meters) of soft soil are located within the planned foundation depth, consider the vertical capacity and long-term settlement.
- If the foundation is located near the edge of a slope, the foundation design length may need to be lengthened. Special studies using LPILE can be performed to evaluate sloping ground effects.
- Special foundation designs should be conducted if the foundation will be located in rock. Fracturing and jointing in the rock and its effects on the foundation resistance must be evaluated. Generally, a drilled shaft or anchored shallow foundation is required for rock.
- If casing is required to maintain hole stability, excavation methods should provide contact with firm, undisturbed soil or rock along the sides and at the bottom when the casing is removed. Sloughing material needs to be removed from the side and bottom of the excavation before concrete is placed.
- For locations where the foundation will be constructed using permanent casing, corrugated metal pipe is preferred for cantilever signs and mast arms to maximize torsional resistance to twisting of the foundation. If smooth casing is used, the length of

the shaft will likely have to be increased to offset the lower torsional resistance. Special studies should be conducted to assess this situation. Hollow cardboard cylinders (e.g., sonotubes) are not permitted for casing the hole.

18.2.4 Sound Walls

Sound walls can range from 10 ft (3 m) to 20 ft (6 m) in height, and can be either cast-in-place concrete or formed from pre-cast concrete panels. These walls are designed to resist high overturning moments from wind loading. Because of the high moments, the sound walls are usually supported on deep foundations; however, spread footings can be used if soil conditions are suitable and sufficient space exists for construction of the footing.

Experience indicates that drilled shaft foundations are often the most efficient foundation type for sound walls. The diameter of the drilled shaft can range from 1.0 ft (0.3 m) to 3 ft (0.9 m), and embedment depths vary from under 5 ft (1.5 m) to 15 ft (4.6 m) depending on soil conditions and the amount of overturning force. Typically, the shafts are spaced at approximately 10 ft (3 m) intervals. Continuous concrete-filled trenches (1.5 ft (0.5 m) wide and 1 to 2 ft (0.3 to 0.6 m) deep) have also been used to support sound walls. More recently, continuous flight auger (CFA) piles have been used as an alternative method to support sound walls.

Design procedures for sound wall foundations are summarized in the 2002 Interim to the *AASHTO Guide Specification for Structural Design of Sound Barriers*. The appendix to the *AASHTO Specifications* provides examples of limit equilibrium methods for both pile and trench foundation designs. The principles of sound wall design follow the same foundation design methods as given in Chapter 16, including seismic evaluations, and the most current *AASHTO LRFD Bridge Design Specifications*.