

Chapter 10 — Foundations

10.1—OVERVIEW

Because of the geology of the State of Nebraska, the vast majority of bridges will be founded on deep foundations. Deep foundations can be composed of driven piles or drilled shafts. Driven piles are the most common, with pipe piles frequently used in sandy soils, and H-piles elsewhere. Drilled shafts are more common in northeast and southeast regions of the state. Helical piles and micropiles may be used when conditions warrants them. Spread footing are seldom used for bridges, but very common for gravity walls and culverts.

10.1.1—Design Responsibility

Designs for foundations are shared between the Geotechnical Engineer, the Bridge Designer, and the manufacturer of the piles, when applicable.

The Pile Layout Sheet shall be cosigned by the Bridge Engineer of Record and the Geotechnical Engineer.

In general, the Geotechnical Engineer is responsible for the determining the foundation type for the soil conditions, the geotechnical capacity of the foundation system, and the minimum penetration depth, where applicable. The Bridge Designer is responsible for the structural capacity of the foundation and any interactions with the structures.

10.1.2—Coordination with the Geotechnical Engineer

The foundation type and preliminary capacity recommendation from the Geotechnical Engineer shall be listed in the BDS. An iterative process is required between the Bridge Designer and the Geotechnical Engineer through the design process to arrive at the optimal foundation design.

Bridge Division has created a coordination sheet for tracking the exchange of information with the Geotechnical Engineer; contact Bridge Division for a copy.

At a minimum, the Geotechnical Engineer shall provide a recommendation based on preliminary structural loads, and a final recommendation of geotechnical capacity and minimum penetration below cut-off (where applicable) based on final design. Additional coordination may be necessary for complex cases.

Bridge Designers shall provide the Geotechnical Engineer with pile loading for each substructure:

- For Piles: Maximum pile load at the maximum pile reaction location (always report compression and report tension when applicable)
- For structures with a design live load of HL-93 provide strength level reactions in the unit kips.
- For structures with other design live loads provide service level reactions in the unit tons.
- For Drilled Shafts: Global loads at the bottom of the footing as well as loads for each individual shaft shall be coordinated with the Geotechnical Engineer. All loads shall be given at both service and strength level using the units kips and kip-ft.

10.1.3—Downdrag Effects

Downdrag is ground settlement relative to a pile. It will result in additional vertical load to be resisted by the pile. Consult with the Geotechnical Engineer if downdrag is a concern.

Common situations where downdrag should be evaluated are listed in Hanigan et al. (2016) as:

- Total ground settlement of 4 in. or more
- Ground settlement of 0.4 in. or more after piles are driven
- Height of embankment of 5 ft. or more above current ground surface
- Soft compressible layer of more than 30 ft.
- Lowering of water table by more than 10 ft.
- Piles longer than 80 ft.

Some solutions that have been implemented by NDOT to counteract downdrag are

- Using CMP sleeves to isolate piles from ground settlement
- Restriking of pile after settlement is complete to break developed skin friction
- Construction sequencing to allow backfill to settle before piles are driven.

10.2—DRIVEN PILES

Driven pile are NDOT's most frequently used deep foundation type. Both end bearing and friction pile are used throughout Nebraska based on geological conditions.

10.2.1—Maximum Spacing

AASHTO LRFD does not provide an upper limit to pile spacing.

A maximum pile spacing for driven pile of 10 ft. may be used as a practical upper limit, except for wing wall piles. Wing walls need not be supported by more than two piles.

The 10 ft. maximum pile spacing in the *BOPP* was determined based on grade beam capacity. For replacement of grade beams where pile spacing may become difficult, larger spacing are allowed if the grade beam reinforcement is modified to account for the longer span.

10.2.2—Minimum Spacing

Preferred minimum pile spacing shall be 3.0 times the nominal dimension. For round piles the nominal dimensions is the diameter, for approximately square piles it is the side length. The minimum pile spacing per AASHTO LRFD BDS shall be maintained.

10.2.3—Battered Piles

Piles may be battered when additional lateral or longitudinal load capacity is required.

The preferred battered pile slope shall be 1H:8V. Other acceptable batters are 1H:4V, 1H:5V, 1H:6V, and 1H:7V. Standard Notes #152 and 153 shall be shown on the Geology Sheet when applicable.

The method to determine the increase in lateral or longitudinal capacity for battered piles can be found from reference materials (Hannigan et al., 2016).

10.2.4—Horizontal Pile Load for Preliminary Design

Table 10.1 lists the maximum horizontal pile capacity (along strong axis when applicable) for common pile sections, soil types, and exposed pile heights. This table may be used with engineering judgment when more specific soil design information is not available. Consult with the Geotechnical Engineer for site specific soil design information if needed.

For Ice affected structures, a more refined geotechnical analysis is generally required because of the large lateral and longitudinal loads to be resisted.

Consideration shall be given to extending span lengths when scour at abutment becomes so large that horizontal loads on pile govern the pile design.

Table 10.1—Pile Lateral Load Capacities based on Soil Capacity
Capacity Measured in kips

Soil	Loose Sand or Soft Clay		Soft Clay			Loose Sand		
Exposed Pile Height	None		4 ft	4 ft	6 ft	6 ft	6 ft	12 ft
Pile Type	Service	Strength & Extreme	Service	Strength	Extreme	Service	Strength	Extreme
Precast Concrete Type 1	11	20	7	12	10	6	10	5
12 in. Steel Pipe Pile	11	20	7	15	12	6	14	5
HP12x53	14	30	10	20	15	8	20	8
HP14x89	18	40	14	30	24	14	35	15

Criteria used to develop Table 10.1:

- 75% fixity where the pile is embedded 1 ft. into the footing
- Loose Sand Soil Properties
 - Density $\gamma = 125$ pcf
 - Angle of internal friction $\phi = 30^\circ$.
- Soft Clay Soil Properties
 - Density $\gamma = 115$ pcf
 - Cohesion $c = 650$ psf
- Deflection limits for no exposed pile length
 - Service Limit State: $\frac{1}{4}$ in.
 - Strength and Extreme Event Limit States: 1 in.
- Deflection limits for scoured out pile condition
 - Service Limit State: $\frac{3}{8}$ in.
 - Strength and Extreme Event Limit States: 1 $\frac{1}{4}$ in.

10.2.5—Ground Vibration when Driving Close to Adjacent Structures

Work through and near MSE fills or structures shall be further coordinated with the Geotechnical Engineer.

Damage may occur when driving close to existing building structures with shallow foundations. Bridge Division has adopted the following limits to limit damage to these structures:

- Building structure located 40 ft. or more from the pile driving location: No damage expected. No special precautions shall be taken.
- Building structure located 20 ft. to 40 ft. from the pile driving location: Damage may occur. Pre-drill to at least 2 ft. below the elevation of the structure’s footing.
- Building structure within 20 ft. of the pile driving location: Damage may occur and special precautions must be taken. Depending on the potential and the nature of the damage, each case must be studied individually.

Alternate foundation types may be considered in coordination with the Geotechnical Engineer at sensitive sites as a low vibration alternative.

10.2.6—Minimum penetration

Minimum penetration depths are frequently specified regardless of adequate bearing resistance in order to ensure other criteria, such as settlement and scour stability, are satisfied. Minimum penetration depth shall be as determined by the Geotechnical Engineer.

10.2.7—Pile Cut-Off Elevations

Pile cut-off elevations shall be specified for each pile. Cut-off elevations may be grouped in the Pile Data Table for piling that have a common cut-off elevation.

Implied elevations such as “varies uniformly” shall not be used. Refer to §7.3.1.7.3 for information about field measured cut-off-elevations.

10.2.8—Test piles

The Geotechnical Engineer may specify test piles based on soil conditions. The Geotechnical Engineer shall specify which piles are to be the test piles. At least one pile per substructure element shall be selected as test piles.

The use of test piles requires dynamic or static load testing. The department most frequently performs dynamic load testing with the use of a PDA.

When test piles are used, production pile lengths with the exception of the selected pile are considered tentative and may be adjusted after the load test.

10.2.9—Steel Piles

10.2.9.1—Corrosive soils

Due to corrosive soils observed in parts of Gage, Johnson, Nemaha, Otoe, Pawnee, and Richardson counties, additional electrochemical testing of soil may be required where steel piling is necessary. Coordination with the Geotechnical Engineer is required for these sites of concern.

10.2.9.2—H-Piles

The standard HP section shall be HP12x53. HP14x89 and HP10x42 may be considered.

Standard H-pile sections are supplied as Grade 50 steel.

If cast steel points are required based on the Geotechnical recommendation, note #171 shall be placed in the Notes on the Pile Layout Sheet.

10.2.9.3—Steel Pipe Piles

The standard steel pipe pile section shall have a minimum exterior diameter of 12 in. and a maximum exterior diameter of 13 in. Nominal shell thickness shall not be less than $\frac{3}{8}$ in. Larger diameters and shell thicknesses may be considered in coordination with the Geotechnical Engineer.

Pipe piles shall conform to the requirements of ASTM A252, Grade 3.

NDOT standard is pipe pile installed with a bottom plate or closed ended, however special site conditions may be better suited for open ended pipe pile.

If exposed pipe piles occur, they shall be filled with concrete. This concrete shall be Class “47B” with a minimum 28 day compressive strength of 3,000 psi. Note #176 shall be placed in the Notes on the Pile Layout Sheet.

10.2.9.4—Splice Details

Splice details must be shown on the Geological sheet when driven steel piles are used. Standard cells are available for detailing in the Geology cell library.

10.2.9.5—Uplift Details

Where practical Bridge Division prefers to design foundations without uplift. For piles with load reversal where the uplift is up to 15% of the design pile bearing, the details shown in Figure 10.1 may be utilized. Piles with larger uplift require coordination with the Geotechnical Engineer. Design uplift shall be listed along with the design pile bearing in the pile data table, uplift shall be listed as a negative value.

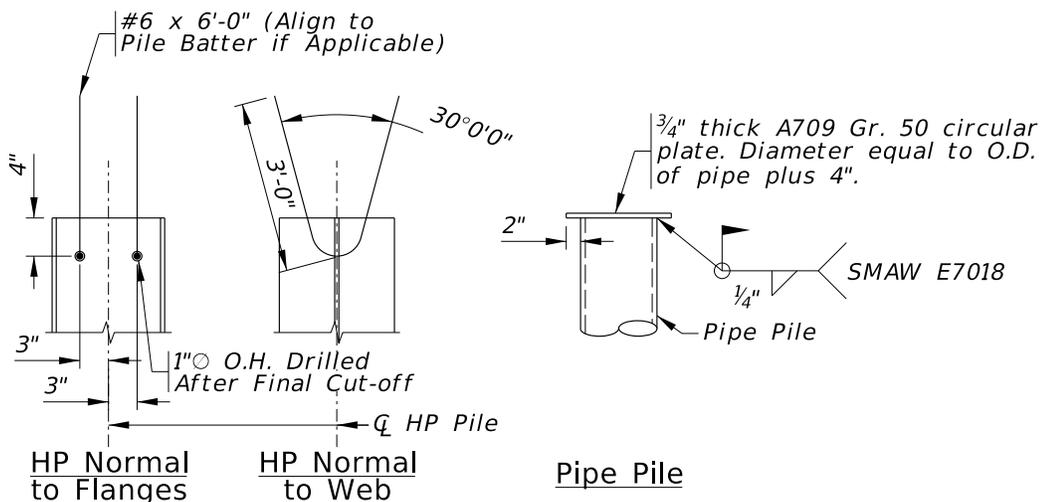


Figure 10.1—Steel Pile Uplift Details

10.2.10—Precast/Prestressed Concrete Piles

The standard Precast/Prestressed Concrete Piles shall be 1 ft. x 1 ft. cross-sectional dimensions with a single 0.5 in. diameter prestressing strand in each corner, 2-#6 mild reinforcing bars on each face at each end, and W5 wire for spiral reinforcement, using 5.0 ksi concrete.

The Concrete Pile base sheet shall be used. If Precast/Prestressed Concrete Piles are used on several bridges on the same project, the base sheet may be treated as its own Special Plan. Otherwise, the base sheet shall be incorporated into the Bridge Plans.

Standard Notes #172, 173, and 174 shall be shown on the Geology Sheet when Precast/Prestressed Concrete Piles are used.

The Precast/Prestressed Concrete Institute provides the free tool “PD01 Calculation of Interaction Diagrams for Piles” for the calculation of prestressed concrete pile interaction diagrams.

10.3—DRILLED SHAFTS

While historically less common than driven pile foundations, drilled shafts are particularly well suited to substructures with heavy design loads, shallow bedrock, and situations with expected depths of scour greater than what can be handled by piles.

Suitability of drilled shafts as foundation elements will be determined in consultation with the Geotechnical Section.

10.3.1—Analysis and Design

The Geotechnical Section will provide skin friction values and end bearing values (if applicable) for vertical design of the drilled shafts and rock sockets. Detailed lateral analysis is also required for drilled shafts and shall be coordinated with the Geotechnical Section.

All drilled shafts shall be designed as columns for combined axial and moment effects, along with shear effects.

Compatibility shall be considered between the lateral deflections in the substructure and the superstructure. This involves careful selection of the allowable limits for lateral deflection of the substructure and drilled shafts.

The use of temporary or permanent casing will be determined in consultation with the Geotechnical Section. Casing pipes are defined by outside diameter and shall have a minimum wall thickness of $\frac{5}{16}$ in. The stiffness and strength of permanent casings can be considered in design if desired. If a casing thickness of greater than $\frac{5}{16}$ in. is required by design, the minimum casing thickness shall be noted on the plans.

10.3.2—Dimensions

Minimum drilled shaft diameter shall be 3 ft. Drilled shaft diameters from 3 ft. to 8 ft. shall be selected in 6 in. increments. Drilled shaft diameters larger than 8 ft. shall be selected in 1 ft. increments. Drilled shaft diameters larger than 10 ft. require Bridge Division approval.

For columns directly connected to the top of drilled shafts, the drilled shaft diameter shall satisfy the following equation.

$$\begin{aligned} \text{Minimum Shaft Diameter} = & \\ & \text{Column Diameter} \\ & + 2 \times (\text{Shaft Concrete Cover}) \\ & + 2 \times (\text{Shaft Horizontal Construction Tolerance}) \\ & + 2 \times (\text{Shaft Cage Thickness}) \\ & - 2 \times (\text{Column Concrete Cover}) \end{aligned}$$

Drilled shafts as complete foundation elements are divided into two components. The upper component is termed drilled shaft, which extends from the bottom of the substructure through the overburden layers to the foundation stratum. The optional lower component is termed rock socket and extends from the bottom of the drilled shaft into the foundation stratum to a depth necessary to achieve the required geotechnical capacity. Rock socket usage is evaluated based on primarily bedrock elevation but also the overburden properties and scour analysis.

It is typically more economical to place columns directly on top of drilled shafts rather than using a footing, but this is not always practical. Consideration should be given to avoiding overly deep cofferdams during construction of water crossings; their use can substantially increase cost.

Frame action and soil-structure interactions shall be considered in the design of drilled shafts. This approach requires an iterative solution rather than arbitrarily selecting points of fixity.

Drilled shafts unit cost increases sharply for shaft diameters greater than 8 ft.

Based on Contractor input, the most cost-effective drilled shaft diameters range from 4 ft. to 6 ft.

This dimensional requirement is for constructibility of the column.

At time of publishing the Drilled Shafts Special Provision currently lists a horizontal construction tolerance of 3 in.

All lengths shall be specified in 6 in increments. Rock socket length shall be a minimum of 1.5 times its diameter, or the minimum length specified by the Geotechnical Section, whichever is greater.

Rock socket diameters shall be a minimum of 6 in. less than the drilled shaft diameters for drilled shafts less than 6 ft. in diameter. For larger drilled shafts, the minimum is 12 in, but coordination with the Geotechnical Engineer is required. This is to facilitate construction.

10.3.3—Details

Portions of drilled shafts above ground level shall be formed. The formed surface shall extend a minimum of 1 ft. below surrounding grade.

Crosshole sonic logging tubes shall be provided for unless otherwise communicated by the Geotechnical Engineer. The general rule is one 2 in. diameter CSL tube per 1 ft. of drilled shaft diameter, with a minimum of three CSL tubes per drilled shaft, though this may vary. The CSL tubes shall be equally spaced around the inside perimeter of the reinforcing steel cage. The layout shall provide adequate space around the CSL tubes for concrete consolidation and shall avoid congested areas.

10.3.4—Reinforcement Details

Drilled shafts and rock sockets shall be reinforced for their full height.

Double reinforcement cages shall not be used.

Longitudinal bars shall be #8 or larger. Cages shall be detailed with a minimum of six longitudinal bars/bundles and shall always have an even number of bars/bundles. The longitudinal bars may be bundled if needed to meet clearance requirements.

When longitudinal bars must be spliced, no more than half of the bars shall be spliced at any location and splices shall be located a minimum of 5 ft. apart. Lap splices of longitudinal reinforcement shall not be used in the following conditions:

- #14 or #18 longitudinal reinforcement
- Locations where minimum spacing requirements cannot be maintained at lap splices

The lap splice information on the base sheet shall be removed in these instances.

Confinement reinforcement can be either circular ties or spirals, though circular ties are preferred. Tie or spiral bar size shall be #4 minimum with spacing determined by design. Spirals are only available up to #6, for reinforcement larger than that ties shall be used. Regardless of longitudinal reinforcement size confinement reinforcement may be placed at up to 12 in. center-to-center.

This requirement also facilitates the sealing of the casing into rock.

See [Table 5.1](#) for concrete strength and mix designation information.

Where possible it is preferred to space CSL tubes between longitudinal reinforcement while still maintaining the minimum spacing necessary to achieve concrete flow. Where this is not possible CSL tubes may be bundled with longitudinal reinforcement.

See [§5.3](#) for clear cover information. Per NHI, constructibility is of paramount concern for drilled shaft detailing and occasionally there are provisions that provide unachievable designs. Typically constructibility will govern over code provisions. The limits shown herein reflect this recommendation (Brown et al., 2018).

Longitudinal bar sizes greater than #11 may be used in drilled shafts and are encouraged to achieve larger spacings between bars that encourage concrete flow.

Tie, spiral, and longitudinal bar size shall be increased as necessary to maintain a minimum clear distance of 6¹/₄ in. between adjacent bars.

For columns with longitudinal reinforcement that anchors into oversized shafts, where bars are spliced by noncontact lap splices, minimum lap length shall be extended by the distance between the longitudinal reinforcement of the column and shaft (McLean & Smith, 1997).

Longitudinal reinforcement projecting from the shaft into the substructure with hooks should be avoided if possible. If hooks are required, consideration shall be given to ensuring that the drop chute or tremie used for concrete placement can be withdrawn and where temporary casing is used it can also be withdrawn.

Where deemed necessary A615 Gr. 80 longitudinal reinforcement may be utilized in drilled shafts by changing the note on the Drilled Shaft base sheet.

10.3.5—Plan Details

The drilled shaft base sheet (with or without rock socket) shall be used and adapted for each project.

Drilled shafts shall include the following plan details for each unique drilled shaft:

- Items provided by Bridge Designer
 - Top of drilled shaft elevation
 - Bill of Bars
- Items provided by Geotechnical Engineer
 - Estimated top of competent rock elevation (if applicable)
 - Estimated bottom of drilled shaft elevation
 - Estimated bottom of rock socket elevation (if applicable)
 - Drilled shaft length
 - Temporary or permanent casing length (if applicable)
 - Rock socket length (if applicable)

10.3.6—Test Shaft

When required by the Geotechnical Engineer, a bi-directional or static load test of drilled shafts may be shown on the plans. The Geotechnical Engineer will provide the Special Provision to be attached to the project on a project-by-project basis.

10.3.7—Special Provision

As the Standard Specifications do not cover drilled shafts, the Geotechnical Engineer will provide the Special Provisions to be attached to the project on a project-by-project basis.

Based on the limited percentage of large aggregate and historical performance of the 47B concrete, NDOT uses 1¹/₄ in. maximum aggregate size for determining minimum bar spacing.

Typically this requires that hooks point towards the interior of the shaft.

When using Gr. 80 reinforcement with mechanical splices the note about prequalified coupler designation requires changes.

Drilled shafts are paid for by the linear foot with reinforcement subsidiary to the cost of the constructed shaft therefore the Bill of Bars is for information only.

When test shafts are used, production drilled shaft lengths are considered tentative and final lengths may be adjusted after the test shaft.

Test shafts may be selected from production shafts, or may require the construction of a non production shaft. Requirements to be coordinated between Bridge and Geotechnical sections.

10.4—HELICAL PILES

Helical piles consist of helical bearing plates attached at the bottom of a high strength central steel shaft. The central shaft is intended to accept applied load and transfer to a bearing soil strata at some depth below the surface.

Grouted columns may be used in addition to bearing plates as part of the helical system in special situations.

10.4.1—Use

Helical piles have been used successfully for supporting grade beams on pile for approach slab replacement projects, when the grade beam piles are the only piles being installed. The helical piles can be installed with limited equipment by Contractors.

For other projects where driven piles are required on other substructure items, it will typically be more economical to install only driven piles. Refer to §7.3.1.7.2 for more details.

10.4.2—Minimum Spacing

For preliminary design, minimum helical pile spacing is 42 in.

10.4.3—Maximum capacity

For preliminary design, maximum helical pile capacity is 50 kips for Strength Load Cases.

10.4.4—Special Provision

The Standard Specifications do not cover helical piles, but Standard Special Provision 7-23-1217 is available for the use of helical piles.

10.5—MICROPILES

Micropiles are small-diameter, high-capacity, drilled and grouted piles used to transfer structural loads into the ground. They are typically less than 12 in. in diameter and consist of steel reinforcement encased in grout.

Micropiles are often employed where access or headroom is limited, soil or rock conditions are challenging, or minimal vibration is desired, such as widening in urban settings.

10.5.1—Use

While not commonly used, micropiles are allowed on State bridges where site conditions warrant their use. They are more commonly used for temporary works.

Pile reactions for substructure members other than grade beams are typically too large to reasonably use helical piles.

Helical piles are also viable for pedestrian structures.

As the helical pile spacing will be significantly smaller than driven pile spacing, the spacing of the helical piles must be verified by the Geotechnical Engineer.

10.6—SPREAD FOOTINGS

Spread footings are seldom used as foundations for highway bridges in Nebraska due to the location of the bedrock. They are common for retaining walls and culverts.

If spread footings are used for bridge substructure elements, the note on the Geology Sheet shall list the maximum bearing as designed, not the maximum allowed by the Geotechnical Engineer.

More guidance on culverts is provided in [Chapter 12](#).

10.7—REFERENCES

Brown, D. A., Turner, J. P., Castelli, R. J., & Loehr, E. J. (2018). *Drilled Shafts: Construction Procedures and Design Methods NHI Course N° 132014 Geotechnical Engineering Circular N° 10* (Technical Report N° FHWA NHI-18-024). WSP USA and National Highway Institute U.S. Department of Transportation Federal Highway Administration. <https://www.fhwa.dot.gov/engineering/geotech/nhi18024.pdf>

Hannigan, P. J., Rausche, F., Likins, G. E., Robinson, B. R., & Becker, M. L. (2016). *Geotechnical Engineering Circular No. 12 – Volume I Design and Construction of Driven Pile Foundations* (Technical Report N° FHWA-NHI-16-009). Ryan R. Berg & Associates and National Highway Institute U.S. Department of Transportation Federal Highway Administration. https://www.fhwa.dot.gov/engineering/geotech/pubs/gec12/nhi16009_v1.pdf

McLean, D. I., & Smith, C. L. (1997). *Noncontact Lap Splices in Bridge Column-Shaft Connections* (Technical Report N° WA-RD 417.1). Washington State Department of Transportation & Washington State Transportation Center (TRAC). <https://www.wsdot.wa.gov/research/reports/fullreports/417.1.pdf>

Last Updated: February 23, 2026