CHAPTER 408

Foundation

NOTE: References to material in 2011 Design Manual have been highlighted in blue throughout this document.

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*Revisions will appear in the next published edition of the *Indiana Design Manual*.

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CHAPTER 408

FOUNDATIONS

A consideration for the satisfactory performance of a structure is the proper selection and design of its foundations that will provide adequate bearing resistance, tolerable lateral and vertical movements, and aesthetic compatibility. This Chapter discusses criteria for the design of structural foundations relative to spread footings, driven piles, and drilled shafts.

408-1.0 GENERAL

The design of a bridge foundation is best accomplished by an interdisciplinary team of structural, hydraulic, and geotechnical engineers. Foundations shall be designed for the specified limit states described in *LRFD*.

The following summarizes the concepts described in *LRFD*.

408-1.01 Introduction

Loads generated as a result of earth pressures can be determined with assistance from *LRFD* Section 11. Then the nominal and factored resistance of the substructure is computed in accordance with *LRFD* Section 10, the *INDOT Geotechnical Manual* (*IGM*), and the INDOT *Load and Resistance Factor Design Policy for Structural Foundations*.

408-1.02 Informational Needs

The expected geotechnical-exploration project requirements shall be developed in accordance with *LRFD* and *IGM*.

408-1.03 Selection of Foundation Type

A spread footing is typically the most cost effective, with the right set of conditions. It functions best in hard or dense soils that have adequate bearing resistance and exhibits tolerable settlements under load. A spread footing is most appropriate where shallow bedrock is encountered.

A spread footing shall be avoided where loss of lateral support and lack of overall stability is a possibility. A spread footing shall be avoided on soft soil or weak rock to support design loads that can create excessive settlements or loss of stability.

If a spread footing is unsuitable or uneconomical for foundation support, driven piles shall be considered.

Drilled shafts may be considered where a deep foundation is required but piles are unsatisfactory due to obstructions, noise, vibrations, voids, or steeply dipping rock. Drilled shafts can be an economical alternative to driven piles where the use of cofferdams is anticipated.

Chapter 402 discusses those types of foundations and the criteria which influence the selection of a foundation type. Other factors to be evaluated in choosing the type of foundation are discussed in Chapter 402.

408-1.04 Load Factors and Load Combinations

The *LRFD* loads, load combinations and load factors for use in foundation design shall be in accordance with *LRFD* Sections 3 and 4.

408-1.05 Limit States and Resistance Factors

The limit state shall be that specified in *LRFD* 1.3.2. The foundation-specific requirements are provided in *LRFD* 10.5 and herein. For the Service and Extreme Limit states, the resistance factor shall be taken as 1.0. A foundation shall be proportioned so that the factored resistance is not less than the effect of the factored loads specified in *LRFD* Section 3.

408-1.05(01) Service Limit State

Foundation design shall be in accordance with *LRFD* 10.5.2.

The resistance factor shall be taken as 1.0, except as provided for overall stability in *LRFD* 11.6.2.3.

A resistance factor of 1.0 shall be used to assess the ability of the foundation to satisfy the specified deflection criteria after scour due to the design-flood event , Q_{100}.

408-1.05(02) Strength Limit State

The design of a foundation element shall include consideration of the nominal geotechnical and structural resistances. Deformations required to mobilize the nominal resistance need not be considered.

The resistance factors for each type of foundation system shall be taken as specified in *LRFD* 10.5.5.2.2, 10.5.5.2.3, 10.5.2., or 10.5.5.2.5, and the Indiana-specific values shown in Figure 408-1A.

The design of a foundation shall consider structural resistance, which includes axial, lateral, and flexural consideration in addition to loss of lateral and vertical support due to scour at the design-flood event, Q_{100}.

Foundation design shall be in accordance with *LRFD* 10.5.3.

408-1.05(03) Extreme Limit State

The design of a foundation shall be consistent with the expectation that structure collapse is prevented and that life safety is protected. It shall be checked as specified in *LRFD* 10.5.4.

408-1.06 Foundation Approval

The procedure and guidelines for a foundation review, the Foundation Review Form, and pile-tip-elevation guidelines are described below.

408-1.06(01) Guidelines for Foundation Review

A foundation review shall be conducted by the designer for each bridge replacement, bridge reconstruction, box structure that can be classified as a bridge, or three-sided structure including that which cannot be classified as a bridge. It shall be conducted once actual loads are available, but not later than the Stage 3 submittal.

The guidelines for conducting a foundation review are as follows.

1. Minimum pile-tip elevations for scour for the interior substructure shall be determined in accordance with the method outlined in Figure 408-3D, the Pile Tip Elevation Guidelines flowchart.

2. The minimum pile-tip elevation for a pile footing shall be determined using the check flood, Q_{500} scour elevation.

3. Where the bottom of a pile footing is located above the design flood, Q_{100} scour elevation, the piling shall be designed as free-standing for the unsupported pile length above the design flood, Q_{100} scour elevation. The resistance factors shall be as described in Section 408-5.0. The piling shall also be checked for the same criteria using the check flood, Q_{500} scour elevation, with the resistance factors described in Section 408-5.0.

4. The minimum pile-tip elevation for scour shall not be confused with the estimated pile-tip elevation theoretically required to obtain the required bearing. The estimated pile-tip elevation appears in the Geotechnical Report. The lower of these two pile-tip elevations shall be used for determining the pay quantity.

5. Proposed top and bottom footing elevations shall be determined in accordance with the procedure described in Figure 408-3D.

6. The mudsill of approximately 12-in. thickness for a wall pier that has a single row of piles can be considered as an open pile bent with a deep cap. Hence, the mudsill need not be placed below the scour elevation.

7. A pier in a floodplain shall be designed as a river pier. Its foundation shall be located at the appropriate depth if there is a likelihood that the stream channel will shift during the life of the structure, or that channel cutoffs are likely to occur. For a structure or portion thereof that qualifies as an overflow structure, contact the Office of Hydraulics.

8. Engineering judgment shall be used in conjunction with Figure 408-3D in recommending pile-tip and footing elevations.

408-1.06(02) Foundation-Review Procedure

The designer will receive the Geotechnical Report. Once actual loads are available and before Stage 3 submittal, the designer shall propose the foundation using Figure 408-1B, the Foundation Review form.

An editable version of this form appears on the Department website at www.in.gov/dot/div/contracts/design/dmforms/.

1. The information to be provided is as follows.

    a. Spread footing.

Type: Spread Footing on Rock, or Spread Footing on Soil
Size: N/A
Factored Design load: The factored bearing resistance, q_R, shall be shown
Nominal Design Load: The nominal bearing resistance, q_n, shall be shown
Minimum pile tip elevation: n/a
Use pile tips: n/a
Bottom of Footing Elevation
Top of Footing Elevation

b. Footing supported on piles or pile bent.
Type: Bent or Pier
Size: dimensions of H or pipe piles, and the shell thickness of pipe piles
Factored Design load: The factored bearing resistance, R_R, shall be shown
Nominal Design Load: The nominal bearing resistance, R_n, shall be shown
Minimum pile tip elevation: As recommended in the geotechnical report
Use of pile tips: As recommended in the geotechnical report
Bottom of Footing Elevation
Top of Footing Elevation

2. The designer shall then transmit the calculated foundation loads and the form to the geotechnical engineer who developed the Geotechnical Report.

3. If the geotechnical engineer approves, he or she signs, dates, and returns the form to the designer. If the geotechnical engineer disagrees with the recommendations, the marked-up form is returned to the designer for resubmission.

4. Once the geotechnical engineer approves the form, the designer transmits a request for a foundation review, with the Stage 3 submittal, which includes the following:

   a. Geotechnical Report's summary of bridge-related items;
   b. General Plan and Layout sheets;
   c. Foundation Review form; and
   d. Scour Review memorandum.

5. The project reviewer reviews the Foundation Review form and signs and dates it once he or she concurs.

6. The project reviewer submits the form to the appropriate Bridge Design supervisor, who transmits it to the Division director. If the Division director concurs with the recommendations, he or she signs and dates the form.

7. The Bridge Design supervisor transmits the completed Foundation Review form to the project manager. The Office of Geotechnical Services shall receive a copy of the approved Foundation Review form.

408-2.0 SPREAD FOOTING

Reference: *LRFD* 5.8, 5.13, 10.5, 10.6

408-2.01 General

A spread footing is considered early on in the design process as a possible economical foundation option if the foundation conditions are suitable. The design of a spread footing is usually an interactive process between the geotechnical and structural designers.

A spread footing shall not be constructed on soils that can liquefy under earthquake loading.

If a spread footing is recommended, the geotechnical engineer will provide the following design recommendations in the geotechnical report:

408-2.01(01) Footing Elevations

The elevations of the proposed footing will be provided along with a description of the foundation materials that the footing is to be constructed on.

408-2.01(02) Nominal and Factored Bearing Resistances

The nominal and factored bearing resistances will be provided for each effective footing width likely to be used.

408-2.01(03) Bearing Resistance and Settlement

Bearing resistance corresponding to 0.5 in. and 1 in. of settlement at the Service Limit state shall also typically be provided unless other settlement limits are established by the designer. The designer shall communicate all footing-settlement limits to the geotechnical engineer.

For soil conditions, the bearings resistance provided assumes that the footing pressures are uniform loads acting over effective footing width, B', and length, L', with (B or L)-2e as determined by the Meyerhof method. For a footing on rock, the resistances provided assume triangular or trapezoidal stress distribution and maximum toe bearing conditions.

Minimum footing setback on a slope or embedment depth shall be provided.

408-2.01(04) Sliding Stability and Eccentricity

The soil parameters shall be provided for calculating frictional sliding resistance and active and passive earth pressures as follows:

Soil Unit Weight, γ, for soil above footing base;
Soil Friction Angle, φ, for soil above footing base;
Active Earth Pressure Coefficient, K_a;
Passive Earth Pressure Coefficient, K_p; and
Coefficient of Sliding, tan δ.

The eccentricity of loading at the Strength Limit state, evaluated based on factored loads shall not exceed the following:

1. 1/4 of the corresponding dimension *B* for a footing on soil; or

2. 3/8 of the corresponding dimensions *B* or *L* for a footing on rock.

408-2.01(05) Overall Stability

The designer shall evaluate overall stability and provide the maximum footing load which can be applied to the design slope. A resistance factor of 0.65 shall be used if a structure is supported over the slope. This shall be as described in *LRFD* 11.6.2.3.

408-2.02 Minimum Dimensions and Materials

408-2.02(01) Spread Footing

The minimum thickness is 1.5 ft.

408-2.02(02) Class of Concrete

The concrete shall be class B.

408-2.02(03) Concrete Strength

The specified 28-day compressive strength, f'_c, is 3000 psi.

408-2.02(04) Reinforcing Steel

The specified minimum yield strength, f_y, is 60 ksi.

408-2.03 Footing Thickness and Shear Design

The footing thickness may be governed by the development length of the footing dowels from the footing to the wall or column, or by concrete-shear requirements. Shear reinforcement shall be avoided. If concrete shear governs the thickness, it is usually more economical to use a thicker footing unreinforced for shear instead of a thinner footing with shear reinforcement. Requirements for determining the shear resistance are provided in *LRFD* 5.8.3 and 5.13.3.6.

408-2.04 Depth and Cover

The vertical footing location shall satisfy the following criteria.

408-2.04(01) Bottom of Footing

The bottom of a footing on soil shall be set below the deepest frost level which is approximately 4 ft.

Where a footing is founded on rock, the bottom of the footing shall be embedded a minimum of 2 ft below the top of the rock. However, if the rock surface slopes more than 1 ft, the minimum embedment shall be 1 ft at the low end and 2 ft at the high end of the footing. Lesser minimum embedments may be used if recommended in the Geotechnical Report.

The bottom of a spread footing shall be at least 4 ft below the flowline of the streambed unless non-erodible bedrock is present. The bottom of a spread footing shall also be below the estimated depth of the check flood scour, Q_{500} scour elevation.

408-2.04(02) Top of Footing

The top of the footing shall have a minimum permanent earth cover of 1 ft.

Where the footing is founded in a rock streambed, the top of the footing shall not protrude above the top of the rock.

The top of the spread footing shall be below the estimated depth of design flood scour, Q_{100} scour elevation.

At a stream crossing where stream-bed materials are susceptible to scour, the top of a pile footing shall be set below what is defined by as the Q_{100} contraction scour.

The top of the footing shall be set sufficiently low to avoid conflicts with the pavement section, including subbase or underdrains.

408-2.05 Soil Pressure

The resultant of triangularly vertical pressures between the footing and the foundation shall be within the middle one-half and middle three-fourths of a footing on either soil or rock, respectively. The soil pressures for such distributions may be calculated according to the formulas provided in *LRFD* 10.4 and 10.6.

The soil-pressure formulas can be used for a footing loaded eccentrically about one axis, e.g., retaining wall or wingwalls. *LRFD* 10.4 and 10.6 provide additional information on the treatment of a footing loaded eccentrically.

The factored bearing resistance and the nominal bearing resistance shall be shown on the General Plan sheet.

408-2.06 Settlement

If varying conditions exist, settlement will be addressed in the Geotechnical Report and the following effects shall be considered.

408-2.06(01) Structural

The differential settlement of the substructure causes the development of force effects in a continuous superstructure. These force effects are directly proportional to structural depth and inversely proportional to span length, indicating a preference for a shallow, large-span structure. They are normally smaller than expected and tend to be reduced in the inelastic phase.

Nevertheless, they are considered in the design, especially negative movements which can either cause or enlarge existing cracking in the concrete deck slab.

408-2.06(02) Joint Movements

A change in bridge geometry, especially for a deep superstructure, due to settlement causes movement in deck joints which shall be considered in their detailing.

408-2.06(03) Profile Distortion

Excessive differential settlement can cause a distortion of the roadway profile that may be undesirable for a vehicle traveling at high speed.

408-2.06(04) Appearance

Excessive settlement can create an appearance of decay, neglect, or lack of safety.

408-2.07 Reinforcement

Reinforcement shall be as described in Chapter 405. Bar-development lengths shall be as shown in Figure 408-2A.

408-2.08 Joints

A footing shall not require expansion joints. Footing construction joints shall be offset 2 ft from expansion joints or construction joints in a wall.

408-2.09 Stepped Footing

The difference in elevation of adjacent stepped footings shall not be less than 0.5 ft. The lower footing shall extend 2 ft under the adjacent higher footing, or an approved anchorage system may be used.

408-2.10 Addition to an Existing Footing

At the interface between an existing footing and a new one, existing concrete shall be removed as necessary to provide adequate development length for lap splicing of existing reinforcement or an approved anchorage system may be used.

Where the substructure of an existing structure is extended, the old footing with respect to the new footing shall be shown on the New Footing Details sheet.

408-2.11 Cofferdam

The purpose of a cofferdam is to provide a protected area within which an abutment or a pier can be built. A cofferdam is a structure consisting of steel or wooden sheeting driven into the ground below the bottom of the footing elevation and braced to resist pressure. It shall be practically watertight and be capable of being dewatered. The sheeting used shall be wood or steel depending upon the depth and the pressure encountered. For more information, see the INDOT *Standard Specifications*. A cofferdam is designed and detailed by the contractor.

408-2.12 Concrete Foundation, or Tremie, Seal

A bridge with foundations located in water requires sheet-pile cofferdams to provide dry conditions for construction of the pier foundations. Under certain conditions, such as loose granular soil, the cofferdam cannot be pumped dry due to high-infiltration flows through the bottom of the excavation. A foundation seal must therefore be placed inside the cofferdam and below the proposed bottom of footing to reduce or eliminate the water infiltration.

At the preliminary field check, the designer shall check with the district construction representative and the geotechnical engineer to determine if a foundation seal shall be investigated for the foundation in question. The geotechnical engineer shall determine the need for a seal and include the recommendation in the Geotechnical Report.

Because the unreinforced seal slab is primarily to provide dry working conditions, its design is based upon the uplift force due to the amount of water displaced by the cofferdam. If a seal is specified as part of the design, the assumed water-surface elevation during foundation construction shall be shown on the plans. This elevation is assumed to be approximately 2 ft above the normal water-surface elevation.

The seal thickness shall be determined such that the weight of the concrete in the seal plus friction, or bond, on the steel foundation piling is equal to 100% of the weight of the water displaced. The minimum thickness of the seal slab shall be 2 ft.

The assumed weight of the concrete shall be 140 lb/ft^3. The resistance force due to friction on the pile shall be equal to F_bDp, if $D < d$, or F_bdp, if $D \geq d$, where F_b is the allowable friction, or bond, stress, d is the H-pile-section depth or the pipe-pile diameter, p is the perimeter, and D is the depth of the seal slab. The allowable service-load bond stress between the steel H-pile or pipe pile and the seal concrete shall be taken as 36 psi.

Tension shall be checked in the concrete seal due to bending moments induced by the force of the water pressing upward on the bottom of the slab minus the weight of the seal concrete. The piles shall be treated as the points of support for the slab. The concrete slab shall be treated as an unreinforced-concrete beam. The maximum service load tension in the seal concrete shall be 25% of $7.5(f'_c)^{1/2}$.

408-2.13 Proof Testing of Rock

Excavation for a spread footing on rock shall be proof tested to check the integrity of the rock. See the INDOT *Standard Specifications* for the proof-testing procedure.

408-3.0 PILES

Reference: *LRFD* 5.13, 6.9, 6.12, 10.7

408-3.01 General

If underlying soils cannot provide adequate bearing capacity, scour resistance, or tolerable settlements, piles may be used to transfer loads to deeper suitable strata through friction or end bearing. The selected type of pile is determined by the required bearing capacity, length, soil conditions, and economic considerations. Steel pipe piles and steel H-piles are most commonly used. Other pile types, such as auger-cast piles or timber, may be considered.

If a spread footing is unsuitable or uneconomical for foundation support, driven piles shall be considered. The geotechnical engineer shall be contacted to determine the most-appropriate pile type, size and nominal resistance to support the desired pile loads. The maximum nominal geotechnical resistances provided in Figure 408-3A are based on past experience of INDOT, dynamic and static load tests, and the factored structural resistance of the pile. These maximum nominal geotechnical resistances shall be used in preliminary design only. The geotechnical engineer shall verify these resistances, based on drivability, for the final design, and shall provide the nominal geotechnical resistances required to achieve the factored design soil resistance.

Typical pile types, sizes, and nominal axial resistances for piles terminating in soil, soft rock, or shale, are listed in Figure 408-3A.

The factored design soil resistance may be increased if the field method of resistance/capacity determination is by static load test and if approved by the Office of Geotechnical Engineering.

For piles seated on hard rock, such as limestone, etc., the maximum nominal geotechnical resistance shall be less than or equal to $0.65A_sF_y$. The maximum factored geotechnical resistance shall be less than or equal to $0.46A_sF_y$. This does not apply to piles seated in soft rock, such as shale, weathered rock, etc.

For friction piles, the geotechnical resistance factors for pile analysis shown in Figure 408-1A shall be reduced by 20% if the number of piles in a pile group is 4 or less.

408-3.02 Types

408-3.02(01) Steel-Pipe Piles

LRFD 5.13.4.5, and 5.13.4.6 for a seismic zone, provide requirements for steel-pipe piles. Additional information appears in *LRFD* 6.9.5 and 6.12.2.3. The following will apply to steel-pipe piles.

1. Usage. These are best suited as friction piles. Depending on the subsurface conditions, the geotechnical engineer shall anticipate that such piles will achieve their capacity through a combination of skin friction and end bearing.

2. Diameter. This shall normally be 14 in. However, 16 in. is also used.

3. Class of Concrete. Pile shells shall be filled with class A concrete.

4. Material Strength. The specified 28-day compressive strength of concrete, f'_c, is 3500 psi. Pile shells shall have a minimum yield strength of 45 ksi for Grade 3.

5. Nominal Axial Capacity and Wall Thickness. The maximum nominal axial geotechnical capacity is provided in Figure 408-3A. The minimum wall thickness for a 14-in. pile shall be 0.25 in. For a 16-in. pile it shall be 0.312 in.

   The designer is expected to perform a preliminary feasibility analysis where a higher bearing capacity is desired, and to notify the Office of Geotechnical Services of the desired bearing capacity prior to the beginning of the soils investigation, which is usually at the preliminary field check stage. This shall also be documented in the field check minutes.

If requested by the designer, the Office of Geotechnical Services may allow nominal geotechnical capacities greater than those shown in Figure 408-3A based on drivability and static-load-test requirement.

The designer shall use a single steel-shell wall thickness where the piling for the different substructure elements is in different nominal bearing-capacity ranges. The recommended wall thicknesses to be used shall be based on assurance of availability.

6. Protection for Exposed Piles. Only fusion-bonded, or powdered epoxy resin, epoxy coating shall be used. The epoxy coating shall be extended to 2 ft below the flow-line elevation. The epoxy coating is vulnerable to handling and driving. Because of the vulnerability of the epoxy coating near the flowline, reinforcing steel shall be included in the top part of the pile. See the INDOT *Standard Drawings*.

7. Construction. The designer shall consider the drivability of pipe piles.

408-3.02(02) Steel H-Piles

The following will apply to steel H-piles.

1. Usage. These are used either where the pile obtains most of its bearing capacity from end bearing on rock or as recommended in the Geotechnical Report. These are also used where there are hard layers that must be penetrated in order to reach an adequate point-bearing stratum.

   A steel H-pile can act efficiently as friction piling due to its large surface area. However, steel H piling shall not be used where the soil consists of only moderately dense material. In such conditions, it can be difficult to develop the friction capacity of the H-piles. Excessive pile length can result.

2. Size. Pile size designations may be HP10, HP12, or HP14. HP12 is used most often.

3. Protection for Exposed Piles. Only reinforced-concrete encasement shall be used. The concrete encasement shall be extended a minimum of 2 ft below the flow-line elevation or as specified in the Geotechnical Report.

4. Steel Strength. The yield strength, F_y, shall be a minimum of 50 ksi.

5. Nominal Resistance and Bearing Capacity. The maximum nominal structural resistance or bearing capacity for steel H-piles shall be as described in *LRFD* Section 6, and based on the structural resistance factors allowed as described in *LRFD* 6.5.5. However, this shall be less than or equal to the maximum nominal geotechnical resistance as shown in Figure 408-3A or in the geotechnical report.

408-3.03 Pile Length

408-3.03(01) Minimum Length

The minimum pile length for an integral end bent shall be that shown in Figure 408-3B. If the minimum length shown in the figure cannot be attained, the designer shall provide calculations to support the use of a shorter length. A minimum core depth of 3 ft into scour-resistant rock shall be used. Pedestals shall not be used.

408-3.03(02) Tip Elevation for Friction Piles

The minimum pile-tip elevation shall be shown on the General Plan sheet's elevation view, based on the scour requirements or the minimum pile-tip elevation requirements specified in Figure 408-3D.

408-3.03(03) Tip Elevation for Point-Bearing Piles

The approximate rock elevation shall be shown at each support location on the General Plan's elevation view.

408-3.03(04) Pile-Tip Elevation for Billed Length

The minimum pile-tip elevation shown on the General Plan for a stream crossing is established to provide adequate penetration to protect against scour. It does not necessarily indicate the penetration needed to obtain the required bearing, which is shown only in the Geotechnical Report. Therefore, the billed length of piling shall be computed based on the lower of the minimum tip elevations shown on the General Plan or the estimated bearing elevation shown in the Geotechnical Report. For a spill-through end bent, the billed length of piling will be based upon the estimated bearing elevation shown in the Geotechnical Report.

408-3.03(05) Pile-Tip-Elevation Guidelines

Figure 408-3D lists pile-tip-elevation guidelines for setting piles for an interior substructure in a body of water. Minimum pile-tip elevations are not shown for the end bents unless recommended in the Geotechnical Report, e.g., due to voids in the bedrock or soft-soil strata located below where the pile capacity is reached.

408-3.04 Design Requirements

408-3.04(01) Battered Piles

Piles may be battered to a maximum of 4 vertical to 1 horizontal. For the outside row of piles in a footing, a batter shall be provided on alternating piles. Where closely-spaced battered piles are used, the pile layout shall be checked to ensure that battered piles do not intersect. Battered piles in a bent cap or a footing shall be centered on the bottom of the cap or footing. Therefore, the tops of such piles will be off-center.

Battered piles shall not be used where extensive downdrag load is expected because such a load causes flexure in addition to axial-force effects. Approximately one-half of the piles in a non-integral end bent cap shall be battered.

408-3.04(02) Spacing and Side Clearance

For H-piles, the enter-to-center spacing shall not be less than the greater of 3 ft or 3 times the pile width. For pipe piles, it shall be not less than the greater of 3.5 ft or 3 times the pile diameter or width. For H-piles used as friction piles in cohesive soil, the center-to-center spacing shall not be less than the greater of 2.5 ft or 3 pile widths. This requirement does not apply to piles driven into shale. A larger pile spacing 6 ft or 6 times the pile width is required. The distance from the side of a pile to the nearest edge of a footing shall be greater than 0.75 ft.

The maximum pile spacing shall not exceed 10 ft. However, if the cap or footing is properly designed for a larger spacing, this restriction need not apply. At a pile end bent, at least one pile shall be placed beneath each beam. The need for this requirement lessens with the increase in depth of the pile cap.

408-3.04(03) Embedment

LRFD 10.7.1.5 specifies that pile tops shall project not less than 1.5 ft into the footing after all damaged pile material has been removed. Embedment of piles into the stem of a wall pier with a single row of piles shall be a minimum of 5 ft.

408-3.04(04) Downdrag, DD, Load

Where a pile penetrates a soft layer subject to settlement, the force effects of downdrag or negative loading on the foundations shall be evaluated. These force effects are fully mobilized at relative movements of approximately 1/4 in. to 1/2 in. Downdrag acts as an additional permanent axial load on the pile. If the force is of sufficient magnitude, structural failure of the pile or a bearing failure at the tip is possible. At a smaller magnitude of downdrag, the pile can cause additional settlement. For piles that derive their resistance mostly from end bearing, the structural resistance of each pile must be adequate to resist the factored loads including downdrag. Battered piles shall be avoided where downdrag loading is possible due to the potential for bending of the pile. If the downdrag force is too large to be included as part of the pile load, the force shall be reduced or eliminated through the use of predrilled holes, special coatings, etc.

408-3.04(05) Uplift Forces

Uplift forces can be caused by lateral loads, buoyancy, or expansive soils. Piles intended to resist uplift forces shall be checked for resistance to pullout and structural resistance to tensile loads. The connection of the pile to the footing shall also be checked. Piles may be designed for uplift if specified in the Geotechnical Report. Pile-construction methods that require preboring, jetting, or spudding will reduce uplift capacity.

408-3.04(06) Laterally-Loaded Piles

The capacity of laterally-loaded piles shall be estimated according to approved methods. Investigations are waived if a sufficient number of battered piles are used to resist the lateral loads.

408-3.04(07) Reinforcing Steel for Pile Footing

Reinforcing steel shall be placed within a minimum of 4 in. cover from the bottom of the pile cap.

408-3.04(08) Pile Tips

To minimize damage to the end of the pile, cast-in-one-piece steel H-pile tips shall be used and shown on the General Plan sheet if recommended in the Geotechnical Report or if recommended during the Foundation Review.

408-3.04(09) Pile-Loads Table

The nominal resistance, R_n, and the nominal driving resistance, R_{ndr}, shall be shown in a table on the Soil Borings sheet. See Figure 408-3C. This information will help ensure that pile-driving efforts during the construction process will result in a foundation adequate to support the design loads. The information to be included in the table is as follows.

1. Factored Design Load, Q_F. This is the factored load from the design computations.

2. Factored Design Soil Resistance, R_R. This is the factored geotechnical soil resistance.

3. Resistance Factor, φ_{dyn}. This shall be based on the method of field construction selected to drive the piles. It shall be as described in Figure 408-1A unless otherwise instructed by the Office of Geotechnical Services.

4. Downdrag Load, DD. This is the downdrag load per pile.

5. Nominal Soil Resistance, R_n. This is the long-term nominal pile-bearing resistance.

6. Downdrag Friction, R_{sdd}. This is the skin friction that must be overcome during pile driving. It is obtained from the Geotechnical Report.

7. Scour-Zone Friction, $R_{S\ scour}$. This is the skin friction due to scour that must be overcome during pile driving. It is obtained from the Geotechnical Report.

8. Relaxation, R_{relax}. This is the relaxation in shale that must be overcome during pile driving. It is obtained from the Geotechnical Report.

9. Nominal Driving Resistance, R_{ndr}. This is the nominal pile driving resistance including all geotechnical losses, or bearing.

10. Testing Method. This is the recommended method reported in the Geotechnical Report and as described in the INDOT *Standard Specifications*.

The nominal driving resistance, R_{ndr}, shall be shown on the General Plan's elevation view using a notation similar to the following: *Piling driven to ______ kip nominal driving resistance,* R_{ndr}. The notation shall match the nominal driving resistance shown in the Soil Borings sheet table. It will not be necessary to show the nominal driving resistance on the other detail sheets.

H-piles are not to be driven to refusal. They are instead to be driven to the required ultimate bearing in bedrock. If the Geotechnical Report shows the elevation of the top of the bedrock, it shall be shown on the General Plan's elevation view.

The information regarding piles shall be shown on the plans in the example format shown in Figure 408-3C.

408-3.04(10) Pile-Load Test

The method of pile testing will be specified in the Geotechnical Report. The designer shall contact the Office of Geotechnical Services in specifying the level of pile testing. The locations of the pile-load test shall be shown in the plans.

408-3.04(11) Pile Footing

The minimum thickness under a pier, frame bent, abutment, or retaining wall is 2.5 ft.

408-3.05 Pile Design for End Bent

Chapter 409 discusses the design of piles for an end bent.

408-4.0 DRILLED SHAFTS

Drilled shafts shall be designed as described in *LRFD* 5.7.4, 10.8

408-4.01 Usage

Drilled shafts may be considered where a deep foundation is required but piles are unsatisfactory due to obstructions, noise, vibrations, voids, or steeply-dipping rock. They can be an economical alternative to driven piles where the use of cofferdams is anticipated. They shall also be considered to resist large lateral or uplift loads where deformation tolerances are relatively small.

Drilled shafts derive load resistance either as end-bearing shafts transferring load by tip resistance or as floating, or friction, shafts transferring load due to side resistance.

408-4.02 Socketed Shaft

A schematic drawing of a rock-socketed shaft is shown in Figure 408-4A. Where casing through the overburden soils is required, the socket diameter shall be at least 6 in. less than the inside diameter of the casing. Reinforcement is required within the rock sockets. For a shaft not requiring casing, the socket diameter may be equal to the shaft diameter.

408-4.03 Belled Shaft

Figure 408-4A also shows a belled section. In stiff, cohesive soil, an enlarged base, bell, or underarm may be used to increase the tip-bearing area to reduce unit end-bearing pressure or resistance to uplift. Where practical, extension of the shaft to a greater depth shall be considered to avoid the difficulty and expense of the belled shaft.

408-4.04 Column Design

Because soft soils provide sufficient support to prevent lateral buckling of the shaft, it may be designed according to the criteria for short columns described in *LRFD* 5.7.4.4. If the drilled shaft is extended above ground to form a pier or part of a pier, it shall be analyzed and designed as a column. The diameter of the column supported by a shaft shall be smaller than the diameter of the shaft. The effects of scour around the shaft shall be considered in the analysis. *LRFD* 10.7.3.13.4 provides criteria for determining the depth to fixity below the ground line for a shaft that extends for a portion of its length through water or air.

408-4.05 Reinforcement

Reinforcement shall satisfy the requirements of *LRFD* 10.8.3.9, 5.7.4, 5.10.11, and 5.13.4.6.

408-4.06 Acceptance Testing

The designer shall work with the geotechnical engineer in developing a special provision for acceptance of the drilled draft.

408-5.0 SCOUR AND FOUNDATION CONSIDERATION

An assessment shall be made of the bridge's vulnerability to undermining due to potential scour. Section 32-3.02 discusses the hydraulic design of a bridge, including the hydraulic scour calculations that will significantly impact the design of its foundations. It discusses scour types, e.g., contraction, local, scour-resistant materials, analytical methods for scour evaluation, and countermeasures for alleviating potential scour. These calculations shall be approved by the Office of Hydraulics.

Bridge-foundation scour shall be designed for considering the 100-year event and the 500-year event that generate the maximum scour depth.

For scour conditions, the following resistance factors, φ, shall be used unless otherwise justified.

1. Design flood, 100-yr scour or overtopping flood: φ = 0.70/0.55.

2. Check flood, 500-yr scour or overtopping flood: φ = 1.0.

3. Extreme Event Limit I, earthquake loading: φ = 1.0.

408-6.0 STRUCTURAL CONSIDERATIONS

Reference: *LRFD* 2.6.4.4.2, 3.7.5, 10.6, 10.7.3.13, 10.8.3.9.2

Scour is not a limit state in the context of *LRFD*. It is a change in foundation condition. All of the applicable *LRFD* limit states shall be satisfied for both the as-built and scoured bridge-foundation conditions.

The consequences of the change in foundation conditions resulting from the design flood for scour shall be considered at all applicable strength- and service-limit states. The design flood for scour is the more severe of the 100-year flood or an overtopping flood of lesser recurrence. The consequences of the change in foundation conditions resulting from the check flood for scour shall be considered at the Extreme Event limits. The check flood for scour shall not exceed the 500-year flood or an overtopping flood of lesser recurrence.

A spread footing shall be used only where the stream bed is extremely stable below the footing, and where the spread footing is founded at a depth below the maximum scour computed in Section 32-3.02(06). A footing may be founded above the scour elevation where it is keyed into non-erodible rock.

The pile cap for a deep foundation, driven-open-pile bent, or drilled shaft, shall be located such that the top of the cap is below the estimated contraction-scour depth. A lower elevation shall be considered where erosion or corrosion can damage the piles or shafts. Where the cap cannot be located below the maximum scour depth, soil loss surrounding the deep foundation results in piles or shafts with unbraced lengths. The unbraced length is equal to the length of the pile or shaft exposed by the scour, plus an estimated depth to fixity. The depth to fixity shall be determined as specified in *LRFD* 10.7.3.13 for driven piles, or *LRFD* 10.8.3.9.4 for drilled shafts. The piles or shafts exposed due to scour shall be designed structurally as unbraced-length columns in accordance with *LRFD* Section 5 for a concrete foundation, or *LRFD* Section 6 for a steel foundation. Unscoured piles or shafts can be considered in structural design as continuously-braced columns.

408-6.01 Pile Lateral Design

The Strength Limit state for lateral resistance is only structural, though the determination of pile fixity is the result of soil-structure interaction.

408-6.02 Battered Piles

Battered piles may be used to resist static lateral loads. However, battered piles shall not be used to resist dynamic lateral loads for a new-bridge foundation. Battered piles shall be avoided where extensive downdrag loads are expected.

408-6.03 Pile-Tip Elevations and Quantities

Pile-length quantities provided are based on the estimated tip elevation shown in the Geotechnical Report, or the depth required for design, whichever is greater. If the estimated tip elevation shown in the Geotechnical Report is greater than the design tip elevation, overdriving the pile will be required. The geotechnical engineer shall be contacted to evaluate driving conditions. A unique special provision may be required to alert the contractor of the additional effort required to drive these piles.

Minimum pile-tip elevations provided in the Geotechnical Report may need to be adjusted lower depending on the results of the lateral, axial, and uplift analysis. This becomes the minimum pile-tip-elevation requirement for the contract specifications. If adjustment in the minimum tip elevations is necessary, or if the required pile diameter is different than what was assumed for the Geotechnical Report, the Office of Geotechnical Services shall be informed so that pile drivability can be re-evaluated.

Lateral loading and uplift requirements can influence the number of piles required in the group if the capacity available at a reasonable minimum tip elevation is not adequate. This will depend on the soil conditions and the loading requirements.

The total factored pile axial loading shall be less than the geotechnical factored resistance, R_R, i.e., φR_n, for a simple situation with no geotechnical losses.

408-6.04 Other Pile-Design Considerations

1. Pile Resistance. Nominal pile resistances shall be provided according to *LRFD* design procedures. The resistance factor shall be provided according to the construction quality-control method recommended in the Geotechnical Report, i.e., dynamic formula, wave equation, pile-driving analyzer, etc. The pile types and sizes selected shall optimize the design, and hence take advantage of the available geotechnical and structural resistances.

2. Downdrag Loads. Pile downdrag loads, due to soil settlement other than that caused by dynamic, or seismic, loading, are added to the factored vertical dead loads on the foundation in the Strength Limit state. Load Factors for downdrag loads will be those recommended by the designer. Transient loads shall not be included with the downdrag loads in either the Strength or Service Limit state calculations. Downdrag loads resulting from liquefaction or earthquake-induced soil settlement shall be considered in the Extreme Event limit state pile design. Downdrag loads resulting from soil liquefaction are different than those caused due to static loading. They shall not be combined in the Extreme Limit state analysis.

   Where downdrag conditions exist, the pile must overcome the frictional resistance in the downdrag zone during installation. Such resistance shall not be included in the calculation of available factored resistance, since, after installation, it reverses over time becoming the static downdrag load.

3. Uplift Capacity. The uplift resistance is the same as the pile friction, or side, resistance. Resistance factors and factored uplift resistances will be provided in the Geotechnical Report. Friction resistance in a downdrag zone shall be considered available for uplift resistance. The geotechnical engineer shall be consulted regarding the ability of the piles to resist uplift forces under static or dynamic loading conditions.

4. Minimum Pile-Tip Elevation. Minimum pile-tip elevations are required to satisfy one or more of the design requirements as follows:

   a. lateral load;
   b. scour;

c. liquefaction;
d. uplift loads;
e. settlement or downdrag; or
f. required soil/rock bearing strata.

The required pile-tip elevations shall be shown on the plans and labeled as Required Pile Tip Elevations. Large lateral loads or other conditions can result in the need for additional piling, or larger piles, in order to satisfy lateral deflection criteria or other requirements. This may result in individual axial pile loads being much less than the maximum factored resistances available, either geotechnical or structural. If pile-tip elevations are needed to satisfy scour, uplift, or other requirements, the piles may need to be driven through dense materials to nominal resistances much higher than needed for supporting only the axial loads. The designer shall contact the geotechnical engineer to determine the most economical foundation design under these conditions.

5. Pile-Group Settlement. Pile-group settlement shall be compared to the maximum allowable settlement. Pile depths or layout shall be adjusted if necessary to reduce the estimated settlement to an acceptable level.

6. Pile-Group Effects. For pile-group lateral-load analysis, use the p-y multiplier methods described in *LRFD* and the FHWA *Manual on the Design and Construction of Driven Pile Foundations*.

7. Pile Spacing. For H-piles in soil, use a minimum spacing of 3 times the pile width. For piles placed in shale bedrock, use 6 times the pile width.

8. Pile-Tip Treatment. Where pile-tip reinforcement is required, specify commercial-cast steel points or shoes, or conical pile tips.

9. Pile-Foundation-Design Recommendations. The geotechnical engineer will provide final geotechnical recommendations in the Geotechnical Report, or earlier in the design process as needed. The following minimum recommendations will be provided.

   a. Pile Resistance. The maximum nominal pile resistance, $R_{n\ max}$, will be provided along with estimated pile lengths for one or more pile types. A modified $R_{n\ max}$ value will be provided as necessary to account for scour or liquefaction conditions. The resistance factor will be provided along with the recommended method of construction control, i.e., dynamic formula, wave equation, etc. Downdrag loads, if present, will be provided along with an explanation of the cause of such loads. The depth or thickness of the downdrag zone will be provided.

b. Nominal Pile-Uplift Resistance. This will be provided either as a function of depth or for a given pile length, typically associated with the minimum tip elevation. The pile-uplift resistance will be provided for normal static conditions and for a reduced-capacity condition such as scour or liquefaction. The resistance factor will be provided.

c. P-Y Curves. The geotechnical engineer shall provide the geotechnical design parameters to develop p-y curves for lateral load analysis using a p-y analysis computer program. Two sets of data may be required, one for static conditions and one for dynamic, or liquefied-soil, conditions.

d. Required Pile-Tip Elevations. These will be provided along with an explanation of their basis. The tip elevations, or minimum pile embedments, shall be checked to see if they shall be modified to satisfy other design requirements, such as:

(1) lateral loading requirements,
(2) settlements,
(3) liquefaction,
(4) scour,
(5) seismic and
(6) axial uplift condition.

Changes to the recommended required tip elevations shall be reviewed by the geotechnical engineer.

e. The following geotechnical-related items will be provided, as necessary.

(1) Wave Equation input, if drivability is performed;
(2) pile tip treatment;
(3) pile-restrike time after initial pile drive; or
(4) recommendations regarding pile setup, relaxation, jetting, preboring, precoring, etc.

408-7.0 SEISMIC DESIGN

Seismic design of each foundation shall be in accordance with the AASHTO *Guide Specifications for LRFD Seismic Bridge Design,* except as otherwise indicated below.

The effects of wall inertia and probable amplification of active earth pressure or mobilization of passive earth masses due to an earthquake shall be considered.

The effects of geotechnical seismic hazard shall be considered. A liquefaction-potential assessment shall be conducted for soils that have been screened to be potentially liquefiable. The liquefaction potential shall be evaluated according to the procedures described in the *IGM*.

The effect of liquefaction-induced down drag can have an effect on the substructure. The additional load on the pile or column elements shall be considered in the design.

The designer shall contact the geotechnical engineer regarding minimization of the effect of soil liquefaction and adaptation of mitigation measures, such as ground modification, utilization of different substructure types, etc., to achieve an economical design.

The settlement of end bents and interior bents shall be considered along with the lateral motions accompanying the design event. The vertical settlement of the substructure can result in additional load on substructure elements, increased rotation of bearing elements, uplift of continuous structures, or excessive superstructure grade changes.

The geotechnical engineer is responsible for evaluating earthquake-induced soil settlement in accordance with the *IGM*.

The bridge-approach embankment is defined as 150 ft from the beginning or end of the bridge in the longitudinal direction. Slope failure of the embankment due to earthquake loads can lead to damage to end-bent components or complete bridge failure. Global stability of the embankment shall be determined utilizing the procedures prescribed in the *IGM*.

Piles may be used to resist both axial and lateral loads. The minimum depth of embedment, together with the axial and lateral pile capacities required to resist seismic loads, shall be determined by means of the design criteria established in the site investigation report. The nominal capacity of the piles shall be used in designing for seismic loads.

Where reliable uplift pile capacity from skin friction is present, and the pile/footing connection detail and structural capacity of the piles are adequate, uplift at a pile footing is acceptable, provided the magnitude of footing rotation will not result in unacceptable performance. Friction piles may be considered to resist intermittent, but not sustained, uplift. For seismic loads, uplift resistance of piles, and shafts, the resistance factor shall be taken as 0.80 or less. The uplift shall not exceed the weight of material, with buoyancy considered, surrounding the embedded portion of the pile.

Condition / Resistance Determination Method		Resistance Factor
Nominal Resistance of Single Pile in Axial Compression, R_n	Driving criteria established by INDOT Dynamic Formula at the end of initial drive condition (EOID) only.	$\varphi_{dyn} = 0.55$
Nominal Resistance of Single Pile in Axial Compression, R_n	Driving criteria established by dynamic test with signal matching at the beginning of re-drive (BOR) INDOT Dynamic Pile Load Test, PDA with CAPWAP	$\varphi_{dyn} = 0.70$
Nominal Resistance of Single Pile in Axial Compression, R_n	Driving criteria established by Static Load Test in combination with INDOT Dynamic Pile Load Test, PDA with CAPWAP	$\varphi_{dyn} = 0.80$
For all other conditions, as described in *LRFD* 10.5		---

Notes:

1. The resistance factors shown above are higher than those included in the AASHTO *LRFD Specifications*.

2. The resistance factors were calibrated based on data developed under the ASD methodology. Since no reliability analysis has been performed on the test data used to develop these factors, the actual reliability obtained by using the factors is unknown, and can be less than what was used to develop the resistance factors included in the AASHTO *LRFD Specifications*.

3. The bases for the calibrated resistance factors are as follows:
    a. INDOT *Final Report of the Pile Driving Analysis Demonstration Projects*, November 1995;
    b. INDOT's long-term successful use of the resistance factors since being adopted as standard practice in 1996;
    c. exclusive use of the Gates driving formula; and
    d, INDOT *Standard Specifications* Section 701.05(a), which requires a re-strike at each bent or pier.

RESISTANCE FACTORS FOR DRIVEN PILES

Figure 408-1A

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FOUNDATION REVIEW, LRFD

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TO:
Manager, Office of Geotechnical Services

FROM:

Route:
Structure No.:
Des. No.:
Construction Project No.:
Over:

It is recommended that the following foundations be used for the structure identified above.

Support	No. 1	No. 2	No. 3	No. 4
Type				
Size, incl. Shell Thickness				
Factored Design Load, Q_F (kip)				
Nominal Design Load, Q_N (kip)				
Min. Pile Tip Elev. for Scour				
Pile Tips	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
Bottom of Footing Elevation				
Top of Footing Elevation				

The structure is on piles, so the Summary of Pile Loading for Geotechnical Testing is completed as shown below. Yes ☐ No ☐ n/a ☐

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SUMMARY OF PILE LOADING FOR GEOTECHNICAL TESTING

Support	No. 1	No. 2	No. 3	No. 4
Pile Size, Type, and Grade				
Factored Design Load, Q_F (kip)				
Factored Design Soil Resistance, R_R (kip)				
Resistance Factor φ_{dyn}				
Downdrag Load, DD (kip)				
Nominal Soil Resistance, R_n (kip) *				
Downdrag friction, $R_{s\ dd}$ (kip)				
Scour Zone Friction, $R_{s\ scour}$ (kip)				
Relaxation of Tip in Shale, R_{relax} (kip)				
Nominal Driving Resistance, R_{ndr} (kip)				
Testing Method	Standard Specifications Section 701.05( )			

The MSE-wall or modular-block-wall factored applied pressure shown on the wall envelope is less than the factored bearing resistance. Yes ☐ No ☐ n/a ☐

Notes:

* In Calculation of DD, $\gamma_p = 1.4$

$$\boldsymbol{Q_F \le Q_{F\,max}}$$
$$\boldsymbol{Q_F \le R_R}$$

To calculate R_n: $$R_n = \frac{R_R + \gamma_P (DD)}{\phi_{dyn}}$$

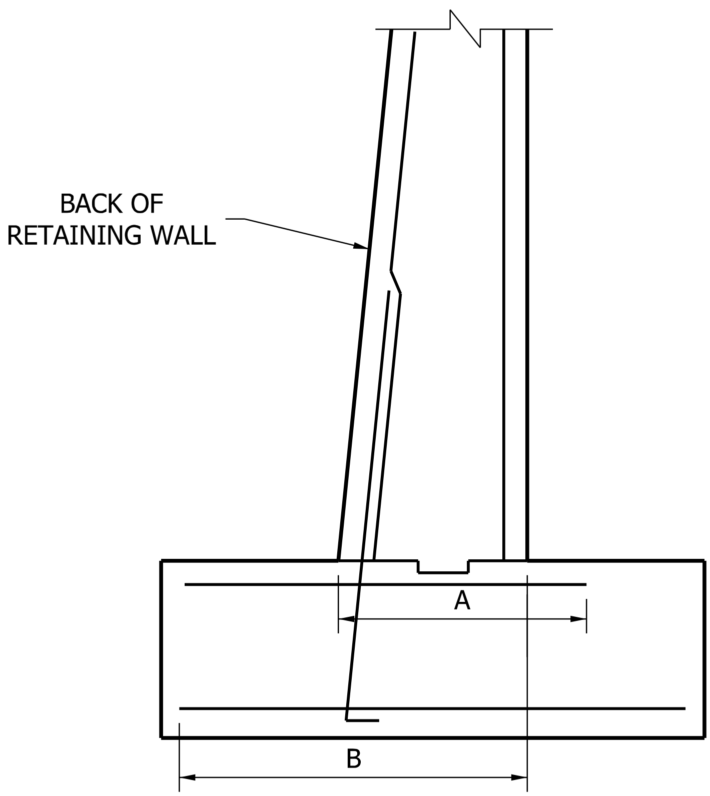
To calculate R_{ndr}: $R_{ndr} = R_n$ + (Geotechnical Losses) ($R_{s\ scour}$ or $R_{s\ dd}$ or $R_{s\ liq}$)

Other:

Approved by: ______________________________ Date:
(Signed) Geotechnical Engineer

Reviewed by: ______________________________ Date:
(Signed) Reviewer, ☐ INDOT ☐ Consultant,

Reviewed by: ______________________________ Date:
(Signed) Director, Bridge



TYPICAL FOR WING
OR STANDARD ABUTMENT

A = STANDARD TENSION DEVELOPMENT LENGTH (MIN.)
B = 1 ½ TIMES STANDARD TENSION DEVELOPMENT LENGTH (MIN.)

BAR DEVELOPMENT LENGTH

Figure 408-2A

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Pile Type	Section Area, in.^{2}	Maximum Nominal Soil Resistance, $R_{n\,max}$, kip
HP 10x42	12.4	341
HP 10x57	16.8	462
HP 12x53	15.5	426
HP 12x63	18.4	506
HP 12x74	21.8	600
HP 12x84	24.6	677
HP 14x73	21.4	589
HP 14x89	26.1	718
HP 14x102	30.0	825
HP 14x117	34.4	946
Pipe pile, 14 in.	n/a	420
Pipe pile, 16 in.	n/a	480

Notes:

1. The resistance factor, Φ_{dyn}, should be used for calculating a pile's geotechnical capacities by means of the field methods. For PDA, Φ_{dyn} = 0.70. For Gates' formula, Φ_{dyn} = 0.55.

2. The maximum nominal capacity and the maximum factored capacity should be dependent on drivability and shell thickness. For a pipe pile of outside diameter 14 in., the minimum shell thickness should be 0.25 in. For a pipe pile of outside diameter 16 in., the minimum shell thickness should be 0.312 in.

3. $R_{n\,max}$ should be taken from the above table. From this value, the maximum factored design soil resistance, $R_{R\,max}$, should be back-calculated with applicable geotechnical losses.

4. The maximum nominal driving resistance, $R_{ndr\,max}$, should be calculated from $R_{n\,max}$ with the applicable geotechnical losses included.

5. Factored design load, Q_F, should be less than the factored design soil resistance, R_R.
   R_R should be less than or equal to $R_{R\,max}$.
   Nominal soil resistance, R_n, should be less than or equal to $R_{n\,max}$.
   Nominal driving resistance, R_{ndr}, should be less than or equal to $R_{ndr\,max}$.

MAXIMUM NOMINAL SOIL RESISTANCE

Figure 408-3A

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Pile Size	Minimum Length, ft	
	Clay	Sand
HP 10	30	25
HP 12	35	25
HP 14	40	30
CFT 14	50	35

MINIMUM PILE LENGTH FOR INTEGRAL ABUTMENTS

Figure 408-3B

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Support	No. 1	No. 2	No. 3	No. 4
Pile Size, Type, and Grade	HP 12 x 53	HP 12 x 53	HP 12 x 53	HP 12 x 53
Factored Design Load, Q_F (kip)	120	160	200	120
Factored Design Soil Resistance, R_R (kip)	120	160	200	120
Resistance Factor φ_{dyn}	0.55	0.55	0.55	0.55
Downdrag Load, *DD* (kip)	12	0	0	0
Nominal Soil Resistance, R_n (kip) *	240	290	363	218
Downdrag friction, $R_{s\ dd}$ (kip)	12	0	0	0
Scour Zone Friction, $R_{s\ scour}$ (kip)	0	7	7	0
Relaxation in Shale (kip)	50	50	50	50
Nominal Driving Resistance, R_{ndr} (kip)	311	348	421	268
Testing Method	Standard Specifications Section 701.05(a)			

SAMPLE SUMMARY OF PILE LOADING

Figure 408-3C

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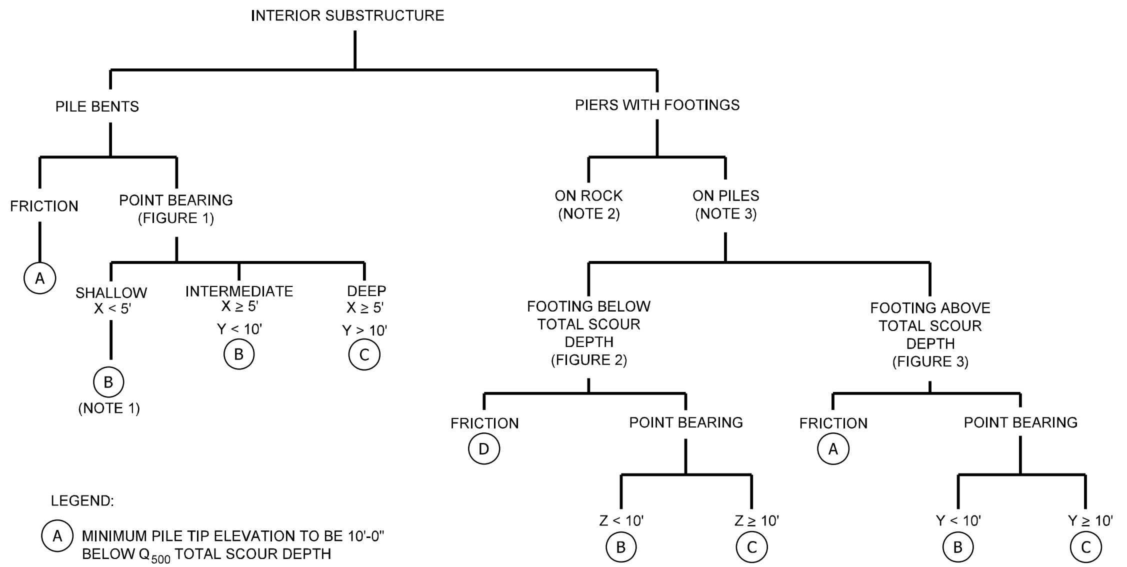

NOTE 1: BOTTOM OF THE PILE TO BE 5'-0" BELOW FLOWLINE.

NOTE 2: BOTTOM OF THE FOOTING TO BE 2'-0" BELOW SCOUR RESISTANT ROCK. THE TOP OF THE FOOTING MUST BE BELOW THE FLOWLINE.

NOTE 3: TOP OF THE FOOTING TO BE BELOW Q_{100} CONTRACTION SCOUR ELEVATION. BOTTOM OF THE FOOTING SHALL BE 6'-0" BELOW FLOWLINE. IF BOTTOM OF THE FOOTING IS ABOVE TOTAL SCOUR DEPTH, PILES MUST BE DESIGNED AS COLUMNS.

LEGEND:

- (A) MINIMUM PILE TIP ELEVATION TO BE 10'-0" BELOW Q_{500} TOTAL SCOUR DEPTH
- (B) MINIMUM 3'-0" CORE INTO SCOUR RESISTANT ROCK
- (C) DRIVE TO ULTIMATE BEARING IN ROCK
- (D) MINIMUM PILE TIP ELEVATION TO BE 10'-0" BELOW BOTTOM OF THE FOOTING

GENERAL NOTES:

1. CORED HOLE IN ROCK SHALL BE BACKFILLED WITH CONCRETE. FOR FRICTION PILE, SIDE FRICTION OBTAINED ABOVE TOTAL SCOUR ELEVATION SHALL BE NEGLECTED.
2. SPREAD FOOTING SHOULD BE INVESTIGATED WHEREVER FEASIBLE.
3. THE BOTTOM OF MUD SILL FOR A WALL PIER ON A SINGLE ROW OF PILES SHALL BE BELOW THE CONTRACTION SCOUR ELEVATION BUT NOT MORE THAN 6'-0" BELOW THE FLOWLINE ELEVATION.
4. THE BOTTOM OF DEBIS WALLS SHALL BE 6'-0" BELOW ORDINARY HIGH WATER BUT NOT MORE THAN 2'-0" BELOW EXISTING CHANNEL BOTTOM.

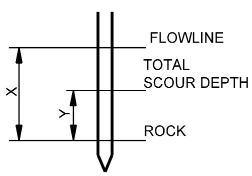

FIGURE 1

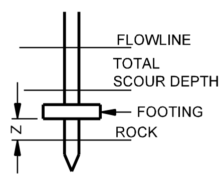

FIGURE 2

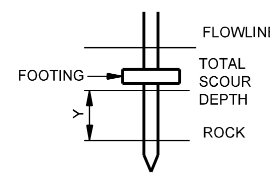

FIGURE 3

PILE TIP ELEVATION GUIDELINES
(For Body of Water)

Figure 408-3D

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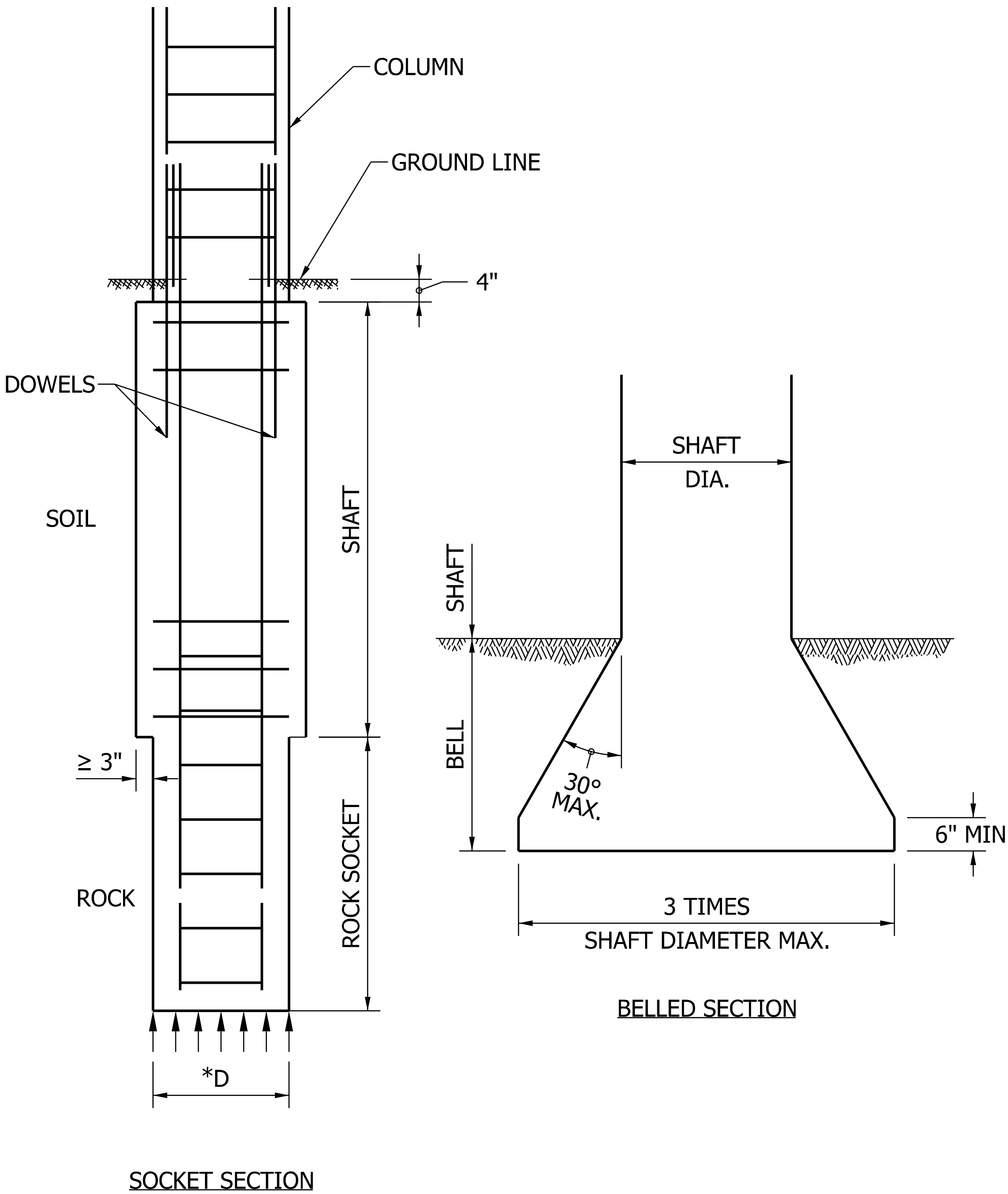

DRILLED SHAFTS

Figure 408-4A