SDG 10:

Bridge Foundation Design

Chapter 10

Tennessee Department of Transportation April 27, 2022

Table of Contents

Table of Figures

List of Tables

Section 1 Foundation Types

The most common foundation types used in Tennessee include:

- Spread footings
- Pile footings on point bearing piles
- Pile footings on friction piles
- Prestressed concrete pile bents
- Steel pipe pile bents
- Drilled shafts
- Seal footings
- Micropiles

Section 2 Spread Footings

Spread footings may be built on rock or soil. The minimum footing depth for spread footings shall be 3'-0".

The nominal bearing resistance given in the foundation report shall be multiplied by the appropriate resistance factor in AASHTO Table 10.5.5.2.2-1 to determine the factored (i.e., allowable) bearing resistance at the Strength Limit State. The resistance factor at the Extreme Event Limit State is 1.0 per AASHTO 10.5.5.3. Do not use service limit state bearing pressures for the bearing pressure design check. The factored bearing resistance must be greater than the Strength and Extreme Event Limit State bearing pressures. Most spread footings are on rock and therefore have a resistance factor of 0.45 at the Strength Limit State.

For example, if a spread footing on rock is assigned a nominal bearing resistance of 40 ksf in the foundation report, the factored bearing resistance would be 0.45 x 40 ksf = 18 ksf. The maximum Strength Limit State bearing pressure shall not exceed 18 ksf for this example.

All bridge footings are eccentrically loaded. For all spread footings, select the Leap Bridge Concrete option shown in Figure 1 to use AASHTO 10.6.1.3. This article helps mitigate the effects of load eccentricity and uplift in footings.

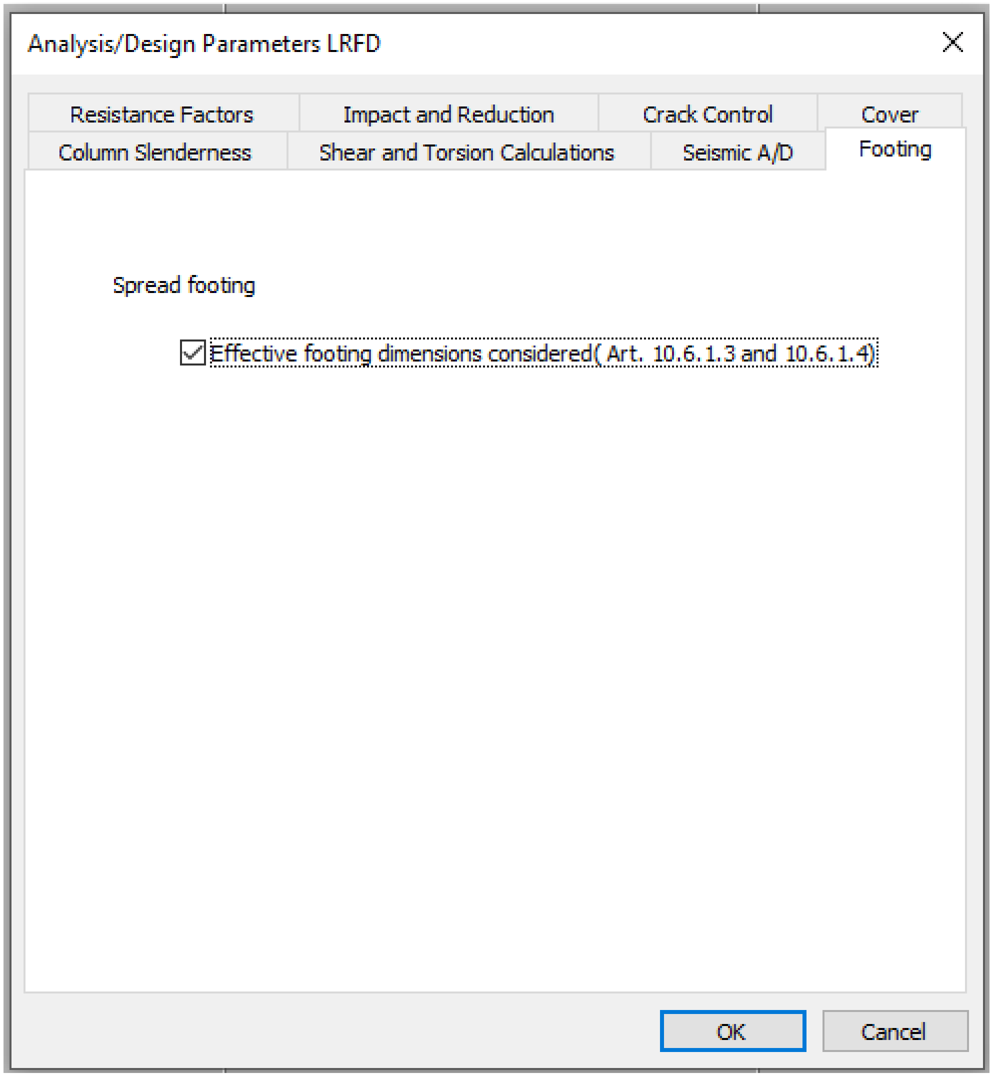


Figure 1. Leap Bridge Concrete Screenshot for Spread Footings

Section 3 Pile Footings

The minimum footing depth for pile footings shall be 4'-0".

10-301.00 Point-Bearing Piles

Point-bearing piles are common in Regions 1, 2, and 3 and are typically HP-piles. Pipe piles are occasionally used in point-bearing applications. The minimum pile length (measured from the bottom of the footing, abutment beam, or wing beam) to the pile tip shall be 7'-0" for driven point-bearing piles. The minimum pile embedment into the footing, abutment beam, or wing beam shall be 1'-0". See Figure 2.

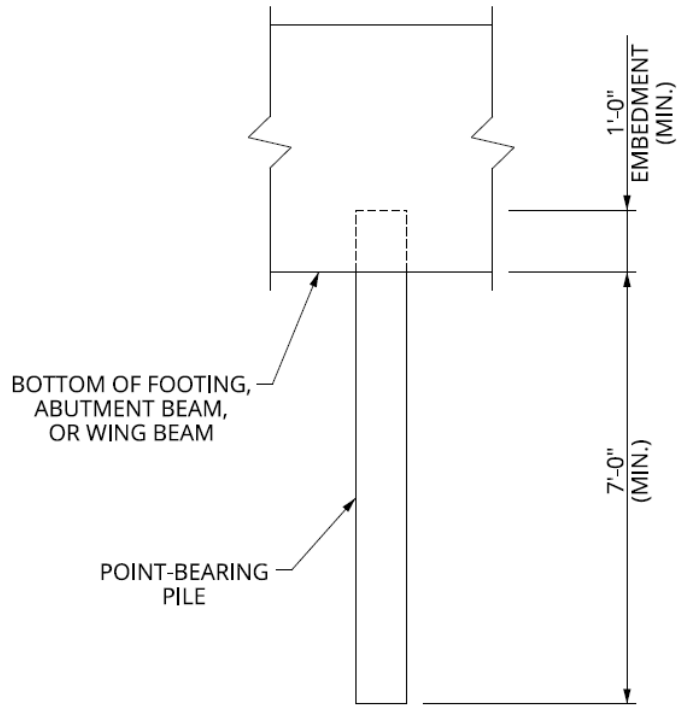


Figure 2. Minimum Point-Bearing Pile Length and Embedment

10-301.01 Driving Force

The driving force, $F_{driving}$, for point-bearing piles shall be taken as:

$$F_{driving} = 0.35F_yA_g \qquad (1)$$

Where: F_y = yield stress of pile = 50 ksi

A_g = area of pile

Using this equation, $F_{driving}$ shall be taken as:

Pile	$F_{driving}$
HP10x42	110 tons
HP12x53	135 tons

Table 1. Driving Force, $F_{driving}$

When designing point-bearing piles, $F_{driving}$ shall be compared to the greater of the Strength and Extreme Event pile reactions.

Pipe piles are primarily used as friction piles. In cases where they are used as point-bearing piles, the driving force for pipe piles shall be calculated using Equation (1) for $F_{driving}$.

10-301.02 Pile Uplift Capacity

Pile uplift forces at the Strength and Extreme Event Limit States shall not exceed 20 kips per pile unless a higher value is determined in accordance with AASHTO.

10-301.03 Pile Lateral Capacity

The lateral capacity of vertical point-bearing piles at the Strength and Extreme Event Limit States shall be calculated using Equation (2).

$$P = \frac{3EI\Delta}{L^3} \tag{2}$$

Where: P = pile lateral capacity at the Strength and Extreme Event Limit States

E = pile modulus of elasticity (ksi)

I = pile moment of inertia about its bending axis (in^4)

Δ = assumed maximum one-way pile head deflection = 1 in.

L = distance from point of fixity to bottom of footing, not to be taken less than 120 in. for this calculation. (in.)

When higher lateral capacity is required, such as for closed abutments, piles shall be battered to resist the lateral forces. The maximum batter (horizontal:vertical) shall not exceed 4:12.

10-301.04 Pre-drilled Point-Bearing Piles

Pre-drilled piles may be considered when a 7'-0" pile length as shown Figure 2 cannot be achieved by pile driving and lowering the footing to be a spread footing on rock is not desired. The minimum pile length (measured from the bottom of the footing, abutment beam, or wing beam) to the pile tip shall be 10'-0" for pre-drilled piles. See Figure 6 in Appendix B for an example of the details to be shown on the bridge plans for pre-drilled point-bearing piles.

10-302.00 Friction Piles

Friction piles are common in Region 4 and are typically prestressed concrete piles or steel pipe piles.

Steel pipe piles shall be ASTM A 252, Grade 3 modified with a minimum yield stress of 50 ksi unless alternate piles are approved by the Design Manager.

10-302.01 Driving Criteria

Unless an alternate method is approved by the Design Manager, the driving criteria shall be established as given below:

Method: A successful static load test of at least one pile per site condition without dynamic testing

Resistance factor, φ_{dyn}, for determining the pile driving criteria at the Strength Limit State: 0.75 (AASHTO Table 10.5.5.2.3-1)

Resistance factor, φ_{dyn}, for determining the pile driving criteria at the Extreme Event Limit State: 1.0 (AASHTO 10.5.5.3.3.)

The required driving load shall be listed on the plans and shall be taken as the greater of:

$$\frac{Maximum\ Strength\ Pile\ Reaction}{0.75}\ and\ \frac{Maximum\ Extreme\ Event\ Pile\ Reaction}{1.0}$$

In the event that driving the test pile to at least the minimum tip elevation or driving the production pile full length might damage the pile because of excessively hard driving, the contractor shall use other methods approved by the engineer for installing the piles such as jetting or pre-drilling holes. However, all piles must be driven by hammer for the last few feet of penetration. No measurement for payment will be made for pre-drilling holes or for jetting piling to obtain the required pile penetration.

10-302.02 Pile Uplift Capacity

Pile uplift forces at the Strength and Extreme Event Limit States are limited to the lesser of:

- the geotechnical capacity of the pile due to side friction in uplift
- the structural capacity of the pile in tension based on the seismic attachment (See STD-6-1.)

The structural steel capacity of the seismic attachment shall be determined using a φ- factor of 0.9 at the Strength Limit State and a φ-factor of 1.0 at the Extreme Event Limit State. For prestressed concrete piles, two seismic attachments are detailed on STD-6-1, but base the structural capacity of the pile attachment in uplift on four C6- bars drilled and grouted 8 feet into the pile and projected 1'-3" above the top of the pile into the footing. The capacity of this attachment is calculated as:

- φT_n = 0.9 × 4 bars × 0.44 in^2/bar × 60 ksi = 95 kips (Strength Limit State)
- φT_n = 1.0 × 4 bars × 0.44 in^2/bar × 60 ksi = 106 kips (Extreme Event Limit State)

When evaluating pile patterns at the Extreme Event Limit State, it is permissible to apply the plastic moment of the column (instead of the over-strength plastic moment) to the footing when hinging is the basis of design. See Article C6.4.2 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design (Guide Specifications) for this allowance.

10-302.03 Pile Lateral Capacity

The lateral capacity of vertical friction piles at the Strength and Extreme Event Limit States shall be calculated using Equation (2) from Section 10-301.03. Battered friction piles are not permitted for bridge foundations. However, battered friction piles are permitted for retaining wall foundations. The maximum batter (horizontal:vertical) shall not exceed 4:12.

Section 4 Pile Bents

Prestressed concrete pile bents are frequently used in West Tennessee. Steel pipe pile bents are occasionally required in Seismic Design Categories C and D when it is difficult to make prestressed concrete pile bents satisfy displacement capacity requirements or when unusually large pile lengths to fixity are required. Prestressed concrete piles for pile bents shall not be designed with a center-to-center spacing less than 5’-0” in order to allow room for an additional pile to be driven between piles if a pile does not reach the required bearing.

Section 5 Drilled Shafts

Cross-hole Sonic Logging (CSL) testing with the addition of 3D tomography shall be performed for all drilled shafts. If CSL testing is indicated on a project with CEI oversight, the CEI firm shall supply a subconsultant that is qualified to perform the testing. If the project does not have CEI oversight, then the Department will supply a consultant to perform the testing. Since the contractor never hires the CSL consultant, CSL testing is never a bid item on the bridge plans. Specify 1 CSL tube per foot of shaft diameter, but not less than 4 CSL tubes. Specify Core Drilling and Sampling (Item Number 204-05.01) at each shaft location as a means of verifying estimated shaft tip elevations.

The Geotechnical Section shall be consulted to determine if permanent casing is required.

The shaft capacity for axial load shall be based on either end bearing capacity or side fiction capacity, but not a combination of both. The minimum rock socket length shall be as directed by the geotechnical engineer, but in no case shall be less than 1.5 times the rock socket diameter.

All drilled shafts shall have a lateral load analysis performed. Contact the Geotechnical Section for more information about this analysis.

Section 6 Cofferdams and Seal Footings

When pier footings are to be placed a significant depth below the water surface, the use of cofferdams is necessary. After constructing the cofferdam, it shall be sealed to make it as nearly water-tight as possible. Pumps are then used to de-water the cofferdam. If the sealing efforts are successful, the cofferdam will remain relatively dry, allowing construction of the structural footing.

For foundations on porous material or fractured rock, de-watering may be impossible as water removed by the pumps is replaced with water forced up through the foundation material. A structural footing cannot be constructed in turbulent or unstable water conditions. In this situation a seal footing shall be required. The seal footing serves to resist the static head created by the water elevation differential between the inside and the outside of the cofferdam.

Prior to pouring the seal footing, the cofferdam is filled with water to an elevation equal to that outside the cofferdam. The hydrostatic pressure is thus stabilized, and the seal concrete shall be poured using a tremie to deposit concrete evenly and uniformly in the bottom of the cofferdam. The structural footing could not be constructed in this manner since the reinforcing would prevent the necessary freedom of movement.

The cofferdam must be de-watered after construction of the seal footing, so the seal footing shall be thick enough to balance the hydrostatic pressure from the water outside the cofferdam. Using unit weights of 62.4 pcf for water and 145 pcf for unreinforced concrete gives a required seal footing thickness of 0.43 times the outside water depth. If the cofferdam is constructed in a manner to provide adequate anchorage to the seal footing, then the cofferdam weight may be included in the calculations to reduce the required seal footing thickness.

When seal footings are required for submerged footings on piles, a portion of the frictional resistance of the piles in uplift may be used in resisting the hydrostatic forces. An upward load test may be required to verify this resistance.

When sizing a seal footing, a 3'-0" work zone shall be provided on two sides of the structural footing on top of the seal. A 1'-6" work zone shall be provided on the other two sides. The 3'-0" work zone gives the Contractor room to place pumps for de-watering the cofferdam. The least plan dimension of the seal shall not be less than half the seal depth.

In cases where it is determined that a seal footing is required, the contract plans shall include bid items for Cofferdams, Class S Concrete (Foundation Seal), and Core Drilling (Concrete Seal). It is common for Rock Excavation (Bridges) to also be required in order to provide the required seal depth.

A typical seal footing is shown in Figure 3. An example of calculations to determine the minimum seal footing depth are given in Appendix C.

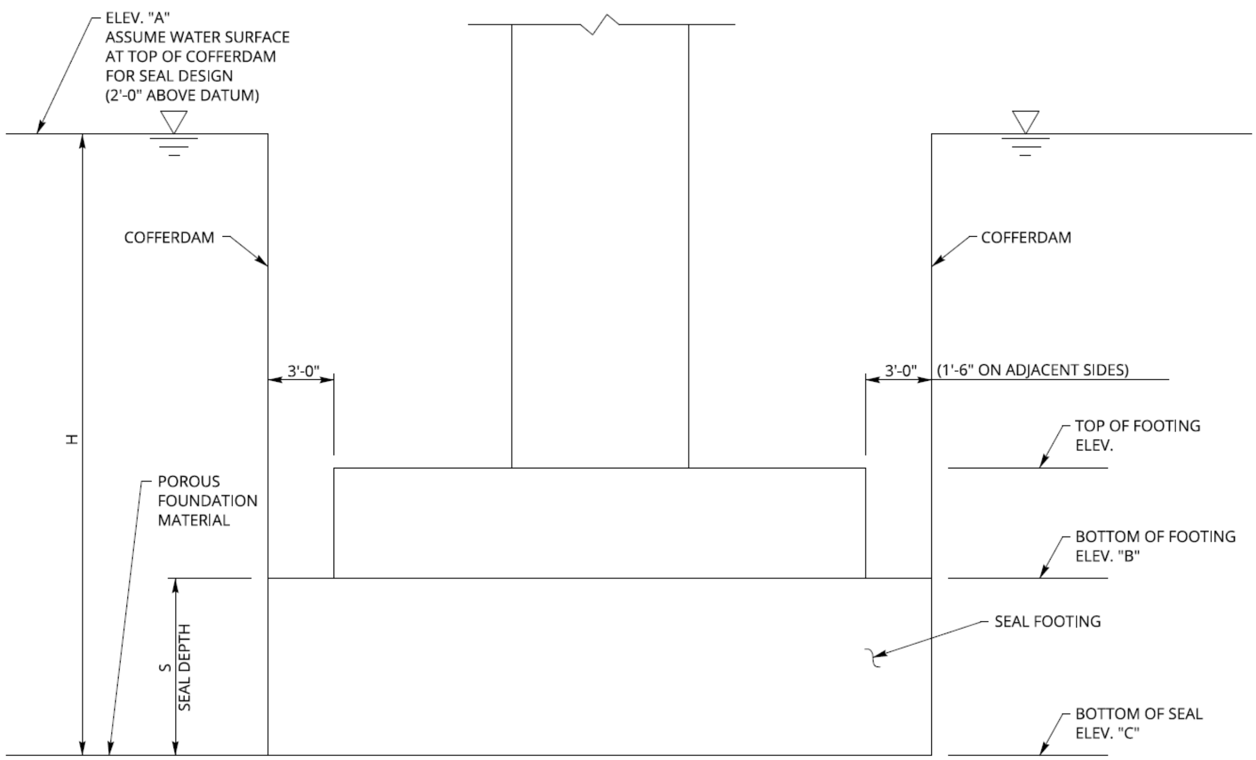


Figure 3. Cofferdam and Seal Footing Details

Section 7 Micropiles

Micropiles are commonly used for accelerated bridge construction (ABC) projects where foundations must be installed under an existing bridge. In these scenarios, there is usually not enough vertical clearance to use a pile driver. Micropiles can be drilled with smaller equipment that requires much less vertical clearance.

Micropiles are usually 9.625" in diameter and include a single high-strength reinforcing bar. They have steel casing for at least part of their length. In order to meet the requirements of the Buy American Act, all casing shall have mill certification to verify that it is of domestic origin. When micropiles are specified on a project, Special Provision SP625MP shall be included in the contract documents. SP625MP is project specific and must be reviewed and edited for each project.

Appendix A: Pipe Pile Design Information

For pipe piles, the fully plastic moment can be calculated with Equations (3) through (9).

- D = outside diameter of pipe
- t = pipe wall thickness
- P_u = axial compressive load on the pile
- F_y = yield stress of the pipe pile material

$$R = \frac{D-t}{2} \tag{3}$$

$$\alpha = \frac{2\pi R F_y t - P_u}{4 R F_y t} \tag{4}$$

$$T = 2R\alpha F_y t \tag{5}$$

$$C = 2R(\pi - \alpha)F_y t \tag{6}$$

$$x_T = \frac{R\sin(\alpha)}{\alpha} \tag{7}$$

$$x_C = \left(\frac{\alpha}{\pi - \alpha}\right) x_T \tag{8}$$

$$M_p = T x_T + C x_C \tag{9}$$

The equation for V_u in Figure 4 can be used to determine the pile embedment, L_e.

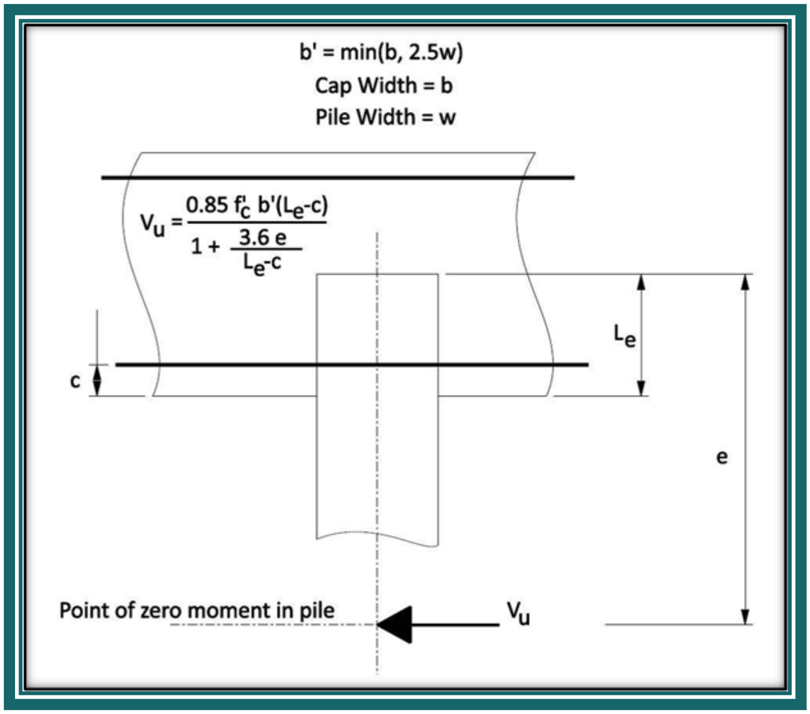


Figure 4. Pile Embedment Requirements

When designing pipe pile bents with high seismic demands, it is common for the piles to be pushed past the elastic limits and become ductile members. In this case it is helpful to fill the piles with concrete to satisfy the limiting width-thickness ratios in Table 7.4.2-1 of the Guide Specifications. Figure 5 shows details that may be used when using pipe piles filled with concrete.

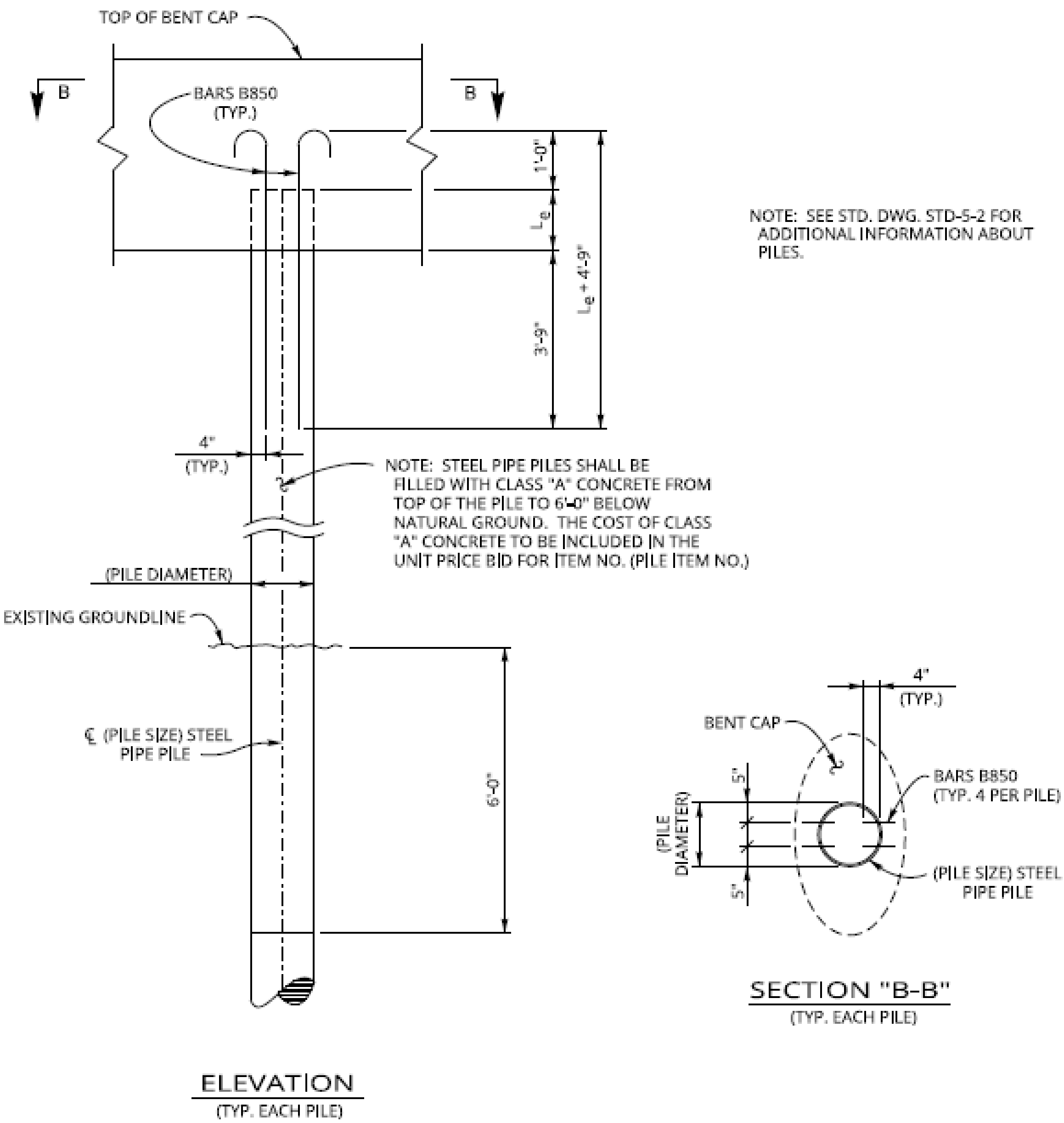
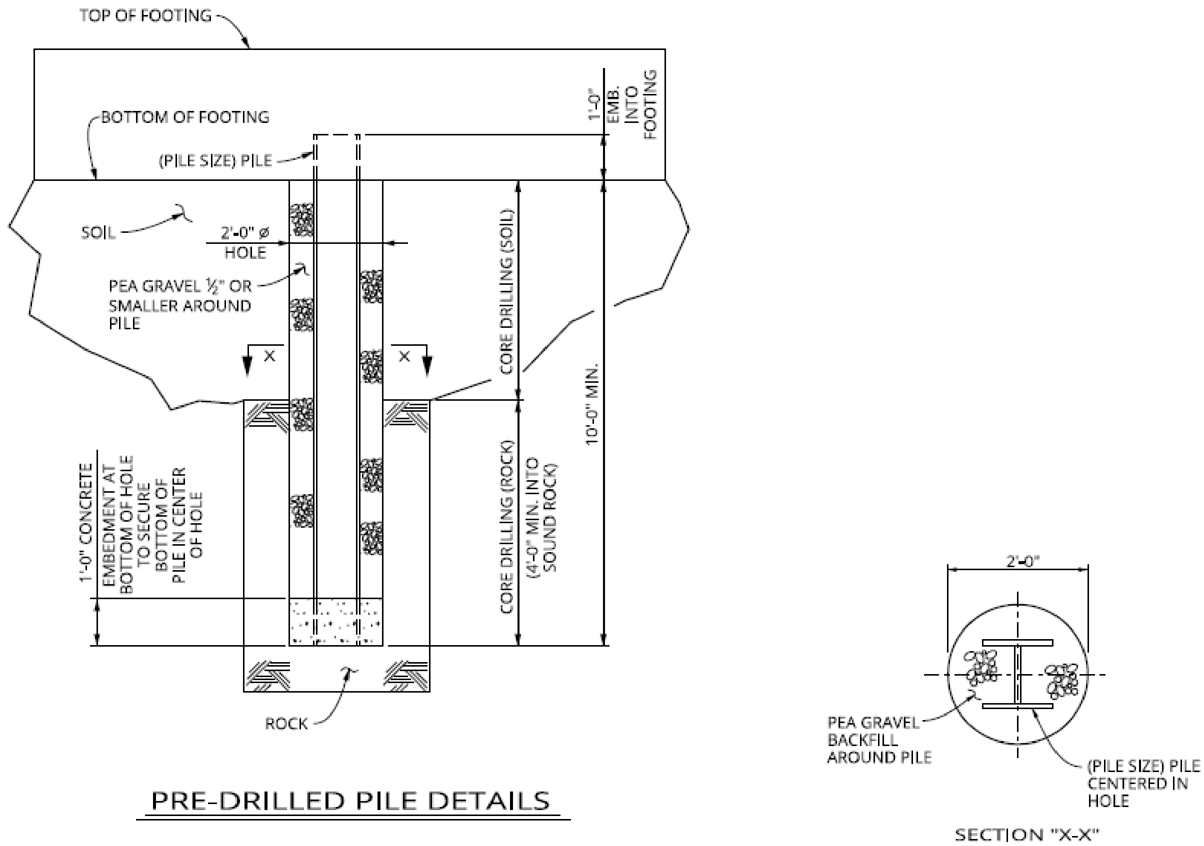


Figure 5. Concrete-Filled Pipe Pile Details

Appendix B: Pre-drilled Point-Bearing Pile Details

An example of typical plans details for pre-drilled piles is given in Figure 6. These details may vary based on recommendations from the Geotechnical Section.



ALL PILES AT (LOCATION) SHALL BE INSTALLED IN ACCORDANCE WITH THE DETAILS ON THIS SHEET. STEEL PILE TIPS (ITEM NO. ________) ARE NOT REQUIRED.

1. A 2'-0" DIAMETER HOLE (10'-0" MINIMUM IN LENGTH) SHALL BE DRILLED IN THE PLANS LOCATION FOR THE PILE. THE AMOUNT OF CORE DRILLING (SOIL) AND CORE DRILLING (ROCK) WILL VARY DUE TO LOCATION OF ROCK LINE.
2. THE HOLE SHALL BE THOROUGHLY CLEANED OF ALL LOOSE MATERIAL, MINIMUM OF 12 INCHES OF HIGH EARLY STRENGTH CONCRETE PLACED IN THE BOTTOM OF THE HOLE, THE PILE INSERTED AND CENTERED IN THE HOLE, AND THE PILE SUPPORTED UNTIL THE CONCRETE REACHES ITS INITIAL SET STRENGTH.
3. AS SOON AS THE CONCRETE HAS OBTAINED ITS INITIAL SET AND IT IS ABLE TO STABILIZE THE PILE TIP LOCATION IN THE BOTTOM OF THE HOLE, THE HOLE SHALL BE BACKFILLED WITH PEA GRAVEL. THE TOP OF THE PILE SHALL BE BRACED IN A MANNER SO THAT ITS VERTICAL POSITION IN THE CENTER OF THE HOLE IS MAINTAINED.
4. CONTRACTOR SHALL TAKE ALL NECESSARY PRECAUTIONS SO AS NOT TO DAMAGE THE EXISTING BRIDGE FOUNDATION DURING PILE PRE-DRILLING. CONTRACTOR IS RESPONSIBLE FOR THE COST TO REPAIR ANY DAMAGED AREAS.

BASIS FOR PAYMENT:
THE COST OF ALL MATERIAL AND LABOR FOR DRILLING THE 2'-0" HOLES, PILE END ENCASEMENT, BACKFILLING WITH PEA GRAVEL, BRACING OF THE PILES, AND ANY OTHER INCIDENTALS REQUIRED FOR FULL INSTALLATION OF THE PILES SHALL BE INCLUDED IN ITEM NO. (PILE ITEM NO. AND DESCRIPTION).

Figure 6. Pre-drilled Point-Bearing Pile Details

Appendix C: Example Seal Footing Depth Calculations

See Section 6 and Figure 3.

Footing size: 4’-0” x 12’-0” x 12’-0”

Seal size: S x 15’-0” x 18’-0”

Elev. “A” = 316.00

Elev. “B” = 300.00

S = 0.43H

H = Elev. “A” – Elev. “B” + 0.43H

0.57H = 16

H = 28.1

Elev. “C” = Elev. “A” – H

= 316.00 – 28.1

= 287.9

Required Seal Footing Depth (S) = 0.43 H = 12.1 ft.

Works Cited

AASHTO, *LRFD Bridge Design Specifications.* 9th. Washington, D. C.: American Association of State Highway and Transportation Officials, 2020.

AASHTO, *Guide Specifications for LRFD Seismic Bridge Design.* 2nd. Washington, D. C.: American Association of State Highway and Transportation Officials, 2011.