IOWA DOT

Office of Design

200F-4

Driven Pile Design

Design Manual
Chapter 200
Geotechnical Design
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Driven piles directly support bridge substructure components and other transportation related structures. Driven piles should be designed according to the Iowa DOT LRFD Bridge Design Manual (BDM) Section 6.2. Pile design is performed by the Office of Bridges and Structures (OBS) or consultants working for OBS using the Soils Design Section S4 submittal consisting of site information, geotechnical analysis, and foundation recommendations developed by the Soils Design Section. The soils information to be included in the S4 Event soils design package that is used by OBS for pile design is outlined in Section 200B-4.

The geotechnical engineer should review the information and understand the specific substructure components: abutments, piers, and sign supports.

The current geotechnical design of driven piles is based on LRFD statistical calibration to static pile load tests completed by Iowa State University (ISU) in 2012.

Quick Tips:

- The Office of Bridges and Structures (OBS) or consultants working for OBS do the actual final pile design. In doing so, OBS relies on the Soils Design Section for a soils design package, S4 Event, containing the boring logs, locations of the borings, soil descriptions, and recommendations used for pile design.
- Iowa DOT pile load tests were used in calibration of the LRFD Pile Design Method.
- Standard Penetration Test hammers averaged about 60% efficiency in the data used for LRFD calibration. Until N_{60} values are available, the designer may use uncorrected N values.

Soils Design Package - S4 Event

The soils design package, S4 Event, is provided for each bridge site by the Soils Design Section for use by OBS for pile design. The S4 submittal typically includes three primary items: 1) Soil Profile Sheets (SPS); 2) Report of Structure Sounding(s); and 3) Supplemental Report of Structure Soundings. The submittal is organized to provide the N values for the Standard Penetration Test and soil descriptions required for pile design. The settlement information on the Supplemental Report includes consolidation time rate information.

Pile foundation recommendations are included in the Supplemental Report of Structure Soundings. The Soils Design Section typically recommends one of the following types of pile, based on how it will achieve its capacity: 1) point-bearing (end-bearing) piles driven to rock; 2) friction piles; or 3) friction plus end-bearing piles. If applicable, the Soils Design Section will discuss downdrag and related design requirements, such as a construction delay period. In addition, the Soils Design Section will define the Structural Resistance Level (SRL) and anticipated rock penetration, as well as recommend if pile driving points are warranted and/or whether the calculated scour as shown on the Situation Plan should be re-evaluated based on the subsurface profile and conditions identified by the soil borings.

Interaction Between the Soils Design Section and OBS in Pile Design

As stated above, the Soils Design Section does not perform the actual pile design (does not pick the final pile size, pile length, number of piles, etc). Instead, most of this final design effort is done by OBS based in part on the information, recommendations, etc. contained in the Soils Design Section's S4 submittal. The subsections that follow discuss efforts that may involve both the Soils Design Section and OBS, and those efforts may relate to input, recommendations, etc. from both the Soils Design Section and OBS.

However, OBS has the primary involvement, and OBS does essentially all items in which the BDM is referenced.

Soil Categories and Descriptions

Geotechnical resistance factors for design (contact length) and for construction (target driving resistance) were statistically calibrated by Iowa State University researchers for three generalized soil categories: 1) cohesive; 2) mixed; and 3) non-cohesive. Therefore, the Soils Design Section must provide a summary of the subsurface conditions, which includes the soil category and soil description to aid in selection of geotechnical resistance factors.

The generalized soil category will be determined as outlined herein, and depends on only the soil considered to be in contact with the side of a pile that will influence the side resistance, or drag loads (if applicable). Soil in contact with the tip for end bearing is not used in determination of the soil category. Any of the following factors can affect the pile length assumed to be in contact with soil: excavation or pre-boring before driving; downdrag; scour; driving refusal at partial pile length, and pile extension. Site soil layering in combination with pile length in contact with soil may cause some unexpected changes in the generalized soil category, and the designer should check multiple possible conditions and apply judgment.

The soil categories for use in design and selection of geotechnical resistance factors include:

- Cohesive: 70% or more of the soil in which the pile penetrates is classified as cohesive according to Table 1.
- Mixed: 31% to 69% of the soil in which the pile penetrates is classified as cohesive according to Table 1 (or 31% to 69% of the soil in which the pile penetrates is classified as non-cohesive according to Table 1).
- Non-Cohesive: 70% or more of the soil in which the pile penetrates is classified as non-cohesive according to Table 1.

Table 1: Soil category based on soil classification.

<table>
<tr><th rowspan="2">generalized soil category</th><th colspan="4">soil classification method</th></tr>
<tr><th>AASHTO</th><th colspan="2">USDA Textural</th><th>Friction Pile Charts BDM Table 6.2.7-2</th></tr>
<tr><td rowspan="13">cohesive</td><td rowspan="13">A-4, A-5, A-6 and A-7</td><td rowspan="13">clay
silty clay
silty clay loam
silt
clay loam
silt loam
loam
sandy clay</td><td rowspan="6">loess</td><td>very soft silty clay</td></tr>
<tr><td>soft silty clay</td></tr>
<tr><td>stiff silty clay</td></tr>
<tr><td>firm silty clay</td></tr>
<tr><td>stiff silt</td></tr>
<tr><td>stiff sandy clay</td></tr>
<tr><td rowspan="7">glacial clay</td><td>firm silty glacial clay</td></tr>
<tr><td>firm clay (gumbotil)</td></tr>
<tr><td>firm glacial clay</td></tr>
<tr><td>firm sandy glacial clay</td></tr>
<tr><td>firm very firm glacial clay</td></tr>
<tr><td>very firm glacial clay</td></tr>
<tr><td>cohesive or glacial material</td></tr>
<tr><td rowspan="7">non-cohesive</td><td rowspan="7">A-1, A-2 and A-3</td><td rowspan="7">sandy clay loam
sandy loam
loamy sand
sand</td><td rowspan="7">alluvium or loess</td><td>stiff sandy silt</td></tr>
<tr><td>silty sand</td></tr>
<tr><td>clayey sand</td></tr>
<tr><td>fine sand</td></tr>
<tr><td>coarse sand</td></tr>
<tr><td>gravely sand</td></tr>
<tr><td>granular material (N > 40)</td></tr>
</table>

Geotechnical and Target Driving Resistances

Geotechnical Resistances

Nominal unit geotechnical resistances for each soil layer will be determined using BDM 6.2.7 and BDM Tables 6.2.7-1 and 6.2.7-2. Thus, the Soils Design Section is responsible for presenting the Structural Resistance Level (SRL) as well as the subsurface data and layer in a manner that OBS can understand and use in pile design. The information to be included within the S4 Event submitted includes Soil Profile Sheets (with Soil Descriptions as outlined in Pile Charts) and Standard Penetration Test N values.

Standard Penetration Test hammers averaged about 60% efficiency in the data used for LRFD calibration; therefore, N_{60} values should be used in design of driven piles. The current Iowa DOT drill rigs have hammer efficiencies near 60%; therefore, no energy correction is made by the Iowa DOT in their pile design. In addition, the Iowa DOT currently does not make the additional overburden correction (to N_{60}) for design of pile foundations on typical projects since the LRFD unit geotechnical resistance values for each specific N value were developed from the 1994 Blue Book, which did not include an overburden correction to the N value for differences in effective stress with depth.

To determine an end bearing resistance value, the designer should average the N_{60} values over a distance eight feet above and below the pile tip. If a pile is designed with end bearing resistance in a soil profile, the pile is driven a minimum of 5 feet into the layer and the designer ensures that the pile tip will not punch through the bearing layer into a weaker layer. If an H-pile is designed with end bearing resistance in bedrock, the pile should be driven with penetration as indicated in the BDM

Table 6.2.4.2-2. If protective pile tips are recommended due to difficult driving conditions, a structural resistance factor of 0.5 will be recommended in lieu of 0.6. Prestressed concrete and steel pipe piles should be driven to bedrock only with approval of the Soils Design Section. Timber piles are not to be driven to bear on bedrock.

The Soils Design Section does not perform a formal settlement evaluation on piles designed using the methods outlined in the BDM since pile stresses in friction piles are designed at a sufficiently low level to maintain settlements within a tolerable level and end bearing piles are extended to fairly incompressible rock materials.

The nominal side and end bearing resistance of driven piles may also be developed based on the results of historical or design phase load test data from the anticipated load bearing soil/rock strata. In order to use historical load test data, the characterized project site soil/rock profile should be similar to the soil/rock profile at the load test site. The Soils Design Section will need to review and approve the use of load test data for development of driven pile capacity. Load testing that can be used to determine nominal side and end geotechnical resistance include static or dynamic (PDA with CAPWAP) load tests.

Target Driving Resistance

The designer must also determine the target nominal driving resistance based on the method of construction control, which usually will be WEAP for Iowa DOT projects. Depending on the general soil type in contact with the pile, which may contribute to set up, the designer will also need to specify one or more nominal re-tap resistances.

Geotechnical Resistance Factors

Iowa State University researchers developed geotechnical and target driving resistance factors from static load tests by statistical calibration, with adjustments based on engineering judgment.

Determine geotechnical resistance factors for axial design using the soils design package and BDM Tables for timber, steel H, prestressed concrete, and steel pipe piles. For end bearing on rock at the strength limit state, use a geotechnical resistance factor of 0.70. For lateral load on a single pile or a pile group at the strength limit state, use a resistance factor of 1.0 [AASHTO-LRFD Table 10.5.5.2.3-1]. Use a resistance factor of 1.0 for the service limit state, except as provided for overall stability in the AASHTO LRFD Specifications [AASHTO-LRFD 11.6.2.3]. Use resistance factors of 1.0 at the extreme event limit state [AASHTO-LRFD 10.5.5.3], except that for uplift resistance of piles, in which case use a resistance factor of 0.75.

Resistance factors for the strength limit state provided in the BDM Tables account for resistance gain due to pile setup for friction piles driven in cohesive soil, and the resistance factors neglect pile setup for friction piles driven in non-cohesive and mixed soil types. Calibration of the resistance factors was based on the target nominal resistance that is achieved at seven days after end-of-drive (EOD). To accommodate Iowa DOT construction practice, it was assumed that planned re-tap tests for construction control would be completed three days after EOD.

Setup Factors for Cohesive Soil

For H-piles driven in cohesive soil, the setup chart and factors outlined in the BDM can be used for estimating the increase in pile driving resistance due to setup after EOD with WEAP construction control. Do not use the chart (BDM, Figure 6.2.10) with Iowa DOT ENR Formula control, or with timber, prestressed concrete, or concrete filled pipe piles.

Other Soil Related Design Issues

Downdrag

Downdrag generally occurs at abutments when placement of approach fill causes settlement of compressible soils below the fill resulting in downward movement of the soil relative to the pile. Downdrag load on the pile may be avoided if the embankment can be placed a sufficient time before abutment piles are driven. The minimum construction delay to allow for settlement to occur prior to driving piles will be determined by the Soils Design Section. If abutment piles must be placed before the approach fill settlement has occurred, consider drag loads as directed by the Soils Design Section for soils above the soil layers labeled incompressible in the soils package for the bridge project. Iowa DOT practice is to apply the full downdrag load to a pile if the settlement in the soil layer is 0.4 in. or greater relative to the pile. Determine downdrag load from the nominal geotechnical resistance chart for friction bearing. Do not use battered piles if downdrag will occur.

Minimum Pile Length

The design penetration for any pile should be a minimum of 10 feet into hard cohesive or dense granular soil and a minimum of 20 feet into soft cohesive or loose granular soil. Piles driven through embankments should penetrate 10 feet into original ground unless refusal on bedrock or a competent layer occurs at a lesser elevation [AASHTO-LRFD 10.7.1.3]. If refusal is encountered before a minimum penetration of 10 feet, the rock should be cored (predrilled) a minimum of 3 feet into the rock formation. The predrilled hole should be a minimum of 6 inches greater in width than the pile. Piles subject to uplift are driven the minimum length to ensure adequate geotechnical tension resistance. The resistance from scourable materials should be excluded when determining the minimum pile length.

Pre-bored Holes

Abutment piles also may be driven in pre-bored holes to reduce downdrag loads due to settlement of the abutment berm. Guidelines for pre-bored hole depths are given in BDM Table 6.2.4.2-1. Pre-bored holes or corrugated metal pipes (CMPs) used to extend piles through the embankment are typically backfilled with sand or bentonite, with the type of backfill determined by the abutment type.

Global Stability

Global stability of the abutment system is performed by the Soils Design Section according to Section 200F-1.

References

1. AASHTO, 2012, LRFD Bridge Design Specifications, American Association of State Highway and Transportation Officials, Sixth Edition, Washington, D.C., USA.
2. Green, Donald, Kam W. Ng, Kenneth F. Dunker, Sri Sritharan, and Michael Nop. (2012). Development of LRFD Procedures for Bridge Pile Foundations in Iowa - Volume IV: Design Guide and Track Examples. IHRB Projects TR-573, TR-583, and TR-584. Institute for Transportation, Iowa State University, Ames, Iowa. http://www.intrans.iastate.edu/research/documents/research-reports/lrfd_vol_iv_final_w_cvr.pdf

Chronology of Changes to Design Manual Section:

200F-004 Driven Pile Design

6/28/2018 Revised

Revised link on page 1 to most recent version of Section 6.2 of the Bridge Design Manual. Corrected references on pages 4 and 5 to tables in the Bridge Design Manual.

1/15/2014 NEW

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