

**NDOT STRUCTURES MANUAL
REVISION 2019-2
March 2019**

Revision Summary

Page(s)	Manual Subsection	Description
17-8	17.2.8	Correct LRFD references. Add requirement for footings to meet joint shear requirements from the AASHTO Guide Specifications for LRFD Seismic Bridge Design.
17-18	17.4.3 - #1	Correct LRFD reference. Clarify drilled shaft structural design requirement.
17-19	17.4.4 - #2	Correct terminology. Add exception for minimum reinforcement. Add reinforcement opening preference.
17-19	17.4.4 - #3	Add requirement for construction joint at the bottom of the column reinforcement.
17-21	17.5	Revise discussion about deep foundation lateral analysis. Add requirement for minimum driven pile and drilled shaft length for lateral stability.

Revisions indicated by underscored text.

17.2.8 Reinforcement

Reference: LRFD Articles [5.10.6](#) and [5.12.8](#)

Section 14.3 discusses NDOT practices for the reinforcement of structural concrete. The design of spread footings shall meet all applicable requirements in Section 14.3. Unless other design considerations govern, the reinforcement in footings should be as follows:

1. Steel in Top of Footing. For pile caps, the anchorage of piles or drilled shafts into footings requires tension reinforcement in the top of the footing to resist the potential negative bending under seismic action. The minimum reinforcement in the top of pile caps and spread footings shall be as required by design but, in no case, less than #6 bars at 12-in spacing.
2. Embedment Length. Vertical steel extending out of the footing shall extend down to the bottom pile cap or spread footing steel and shall be hooked on the bottom end regardless of the footing thickness.
3. Spacing. The minimum spacing of reinforcing steel in either direction is 6 in on center; the maximum spacing is 12 in on center.
4. Vertical Footing Reinforcement. In addition to the provisions of LRFD Article [5.7.3](#), the following shall apply: The minimum vertical reinforcement for spread footings and pile caps shall be #5 bars at 36-in spacing in each direction. The footing joint shear stress and reinforcement shall meet the requirements of Section 6.4.5 and 6.4.7 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design. The extension of the column transverse reinforcement and the minimum vertical reinforcement for column spread footings and pile caps of #5 bars at 12-in spacing in each direction in a band between “d” of the footing from the column face and beginning 6 in maximum from the column reinforcement, is shown in Figure 6.4.7-1 of the AASHTO Guide Specifications for LRFD Seismic Bridge Design. Vertical bars shall be hooked around the top and bottom flexure reinforcement in the footing or cap using alternating 90° and 135° hooks. See the *NDOT Bridge Drafting Guidelines* for typical detailing. These vertical bars enhance seismic performance and are not necessarily for shear resistance.
5. Tremie Seal. Where a tremie seal is used and there are no piles, the bottom footing reinforcement shall be 6 in above the bottom of footing. Where a tremie seal is used and there are piles extending through the tremie, the reinforcement shall be placed above the top of piling.
6. Other Reinforcement Considerations. LRFD Article [5.12.8](#) specifically addresses concrete footings. For items not included, the other relevant provisions of Section 5 should govern. For narrow footings, to which the load is transmitted by walls or wall-like bents, the critical moment section shall be taken at the face of the wall or bent stem; the critical shear section is a distance equal to the larger of “ d_v ” (d_v is the effective shear depth of the footing) or “ $0.5d_v \cot \theta$ ” (θ is the angle of inclination of diagonal compressive stresses as defined in LRFD Article [5.7.3.4](#)) from the face of the wall or bent stem where the load introduces compression in the top of the footing section. For other cases, either LRFD Article [5.12.8](#) is followed, or a two-dimensional analysis may be used for greater economy of the footing.

1. Column Design. Because even soft soils provide sufficient support to prevent lateral buckling of the shaft, drilled shafts surrounded by soil may be designed according to the criteria for short columns in LRFD Article 5.6.4.4 when soil liquefaction is not anticipated. If the drilled shaft is extended above ground to form the lower portion a pier, it should be capacity protected to resist the column overstrength forces to avoid being designed as a column. Similarly, the effects of scour around the shafts must be considered in the analysis.

2. Reinforcement. Section 14.3 discusses NDOT practices for the reinforcement of structural concrete. The design of drilled shafts shall meet all applicable requirements in Section 14.3. Additional reinforcement criteria include:
 - The shaft will have a minimum reinforcement of 1% of the gross concrete area and the reinforcement will extend from the bottom of the shaft into the pile cap. The minimum shaft reinforcement may be reduced to minimum specified in LRFD Article 5.11.4.5.4 if approved by the Chief Structures Engineer.
 - For confinement reinforcement, use spirals (up to #7) or butt-welded hoops.
 - The design and detailing of drilled shafts must conform to the clearances for reinforced steel cages as specified in the *NDOT Standard Specifications*:
 - + 4 in for drilled shafts having a diameter of less than 5 ft, or
 - + 6 in for drilled shafts having a diameter of 5 ft or more.Non-corrosive rollers will ensure that the annular space around the cage is maintained.
 - Detail drilled shafts and columns to accommodate concrete placement considering the multiple layers of reinforcing steel including lap splices. Maximize lateral reinforcement spacing, it is preferred that the openings between the reinforcement are close to 5 inches in both directions. Consider recommendations from the Association of Drilled Shaft Contractors.

Figure 17.4-A illustrates the typical drilled shaft and column longitudinal and transverse reinforcement.

3. Construction Joints. Do not use keys in the design of construction joints for drilled shafts. Drilled shafts supporting a single column shall have a mandatory construction joint at the bottom of the column reinforcing cage.

17.5 MODELING FOR LATERAL LOADING

In the initial stages of bridge design, when using driven piles or drilled shafts, estimate the preliminary point-of-fixity near the top of the pile (bottom of the column). For final bridge design, the structural analysis shall include deep foundation flexibility. The lateral behavior of the deep foundations shall be determined from a lateral soil-structure interaction analysis that considers site specific soil parameters, foundation stiffness, and the design loads.

An example model using non-linear soil “springs,” as represented in Figure 17.5-A. Figure 17.5-B shows a sample set of p-y curves. The soil resistance “p” is a non-linear function of the corresponding horizontal pile deflection “y.”

NDOT uses computer software (e.g., StrainWedge, LPILE Plus, COM624P) to model soil-structure interaction. The interaction between the Structures Division and the Geotechnical Section is discussed in Sections 17.1.4.3.2 and 17.1.4.3.3.

The minimum length, L_{min} , for lateral stability of driven piles and drilled shafts (hereafter referred to collectively as “piles” for simplicity) shall be determined by investigating the effect of pile length on pile stiffness for Strength and Extreme Limit States. The “top of pile” hereafter refers to the top of pile when the top is at or below the ground surface, and refers to the pile at the ground surface when the pile extends above the ground surface. The procedure for calculating L_{min} is as follows:

1. Increase the pile maximum factored loads, Q (i.e. column overstrength moment and shear), by dividing by a p-y resistance factor of 0.8. This provides the lateral stability analysis loads, Q_{Lat} .
2. Iterate the soil structure interaction analysis varying the length of the pile in one diameter increments and determine the displacement at the top of the pile due to Q_{Lat} . The minimum displacement, δ_{min} , is reached when the change in displacement is less than 2% different than the previous iteration (with a one diameter shorter length). The maximum displacement, δ_{max} , is reached at the shortest length of pile that will converge in the analysis and provide a displacement. The minimum displacement, indicating the highest lateral stiffness, is commonly achieved by a pile length of approximately ten diameters. The maximum displacement indicates the shortest length of the pile before failure.
3. Determine the 75% stiffness length, L_{75} . If δ_{max} is more than $1.33\delta_{min}$, then L_{75} is the length of pile that has a displacement equal to $1.33\delta_{min}$. Otherwise, L_{75} is taken as the length of pile at δ_{max} .
4. Determine the minimum length, L_{min} . If δ_{max} is more than $2\delta_{min}$, then L_{min} is L_{75} plus one pile diameter. Otherwise, L_{min} is L_{75} plus two pile diameters.

Additionally, the pile with length L_{min} must have a displacement at the top of pile due to Q_{Lat} less than 10% of the pile diameter. The displacement at the tip of pile due to Q_{Lat} must also be less than 1% of the diameter.

The loads and length calculated above are only for determining the minimum pile length required for lateral stability. Other criteria, such as vertical loads or structure stability, may require a longer pile length. The pile does not need to be designed structurally for the loads used in this analysis, since they are only for the evaluation of stability. A similar lateral stability evaluation is discussed in more detail in FHWA GEC 010. The required minimum lengths from the method specified above will be similar to, but longer than, those required by FHWA GEC 010. The additional length is necessary to increase the factor of safety that, in some cases, may be lower than desired using the FHWA GEC 010 method.

Displacement vs Pile Length

