# SECTION 10: FOUNDATIONS

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## 10.1 Scope

This Section contains guidelines to supplement provisions of Section 10 of the AASHTO LRFD Bridge Design Specifications for the analysis and design of foundations for highway structures. Provisions of this section shall apply to the design of spread footings, driven piles, and drilled shaft foundations.

Bridges that are designed based on soil-structure interaction principles shall be approved by ADOT Bridge Group prior to being accepted to be used to span over roadways.

## 10.4 Soil And Rock Properties

Geotechnical Reports shall be as per the ADOT Geotechnical Project Development Manual on the ADOT Bridge Group website, (Geotechnical Services LRFD Design Memorandums).

## 10.5 Limit States And Resistance Factors

10.5.2 Service Limit States

10.5.2.2 Tolerable Movements and Movement Criteria

Rotational movements shall be evaluated at the top of the substructure unit and at the deck elevation.

Tolerance of the superstructure to lateral movement will depend on bridge seat or joint widths, bearing type(s), structure type, and load distribution effects.

The bridge designer should limit the settlement of a foundation per 100 feet span to 0.75 inch. Linear interpolation shall be used for other span lengths. Higher settlements may be used when the superstructure is adequately designed for such settlements. Any settlement that is in excess of 4.0 inches, including stage construction settlements if applicable, must be approved by ADOT's Bridge Group. The designer shall also check other factors, which may be adversely affected by foundation settlements, such as rideability, vertical clearance, and aesthetics.

Based on the ADOT Bridge Group's recommendation, the settlement, which shall be used for the structural evaluation of any span, shall be the larger of the two settlements at either end of that span. Settlements shall be determined from the charts which are included in the geotechnical foundation report based on service limit state. For settlements in excess of 0.75 inches per 100 feet of span length, the superstructure shall be designed to sustain the forces induced due to such settlement. The bridge designer should use the full value of the settlement without deducting 0.75 inches per 100 feet of span length.

For bridges that will be built using a stage construction method, settlements that do not induce forces in the superstructure may be subtracted from settlements obtained from the geotechnical foundation report when determining the value of the settlement to be used in designing the superstructure.

For bridges involving complex stage construction, the bridge designer should coordinate with the geotechnical engineer when determining settlements.

10.5.5 Resistance Factors

10.5.5.2 Strength Limit States

10.5.5.2.4 Drilled Shafts

In general, a bridge abutment or pier foundation consisting of two or more drilled shafts is considered as a redundant foundation, unless the center-to-center spacing of the drilled shafts is six shaft diameters or more.

Substructure systems spanning roadways, such as straddle bents, and supported by single drilled shafts at each end, shall not be considered redundant.

## 10.6 Spread Footings

10.6.1 General Considerations

10.6.1.1 General

For foundation units situated in a stream, spread footings may be used when they can be placed on non-erodible rock. Spread footings used as bridge foundations shall not be supported by embankment fill material including embankments consisting of mechanically or otherwise stabilized earth systems.

The bridge designer shall size the footing to ensure that the limit bearing pressure and settlement will not be exceeded for any AASHTO LRFD group loading. The footing shall be properly designed to resist the maximum applied moments and shears.

Spread footings shall be designed for limit states and resistance factors as specified in AASHTO LRFD Article 10.5. Resistance factors for the strength limit state shall be taken as specified in AASHTO LRFD Table 10.5.5.2.2-1. Resistance factors for the service limit state shall be taken as 1.0.

For the purpose of determining the bearing resistance, for both service limit state and strength limit state, the bridge designer shall provide the footing length (L) and depth of embedment ($D_f$) within 20 percent plus or minus to the geotechnical engineer. After receiving the above mentioned information from the bridge designer, the geotechnical engineer shall calculate the bearing resistance for the service limit state (for 0.25 inch, 0.50 inch, 0.75 inch, 1.00 inch, 1.50

inch and 2.00 inch settlements) and for the strength limit state. If more than 2 inches of settlement is required, the bridge designer shall coordinate with the geotechnical engineer to obtain bearing resistance for those settlements for the service limit state.

The bridge designer shall design the spread footing based on the bearing resistance provided by the geotechnical engineer and in accordance with the memorandums on the ADOT Bridge Group website.

This Geotechnical Design Policy SF-1 memorandum is available on the ADOT Bridge Group website, (Geotechnical Services LRFD Design Memorandums).

Bridge designers shall include the following information per footing on the structure plan sheets:

- Total settlement which is used in the design of the footing based on the geotechnical report.
- The service limit state factored net bearing resistance (capacity) (in ksf) and the strength limit state factored net bearing resistance (capacity) (in ksf) which are used in the design of the footing based on the geotechnical report.

10.6.1.2 Bearing Depth

If spread footings are deemed acceptable at stream crossings then the footings shall be constructed at a depth of at least 2.0 feet below the maximum anticipated depth of scour as determined by the Bridge Hydraulics Engineer and Geotechnical Engineer.

The bottom of spread footings shall be set at least to the depth recommended in the geotechnical foundation report. The minimum top cover over the top of the footings shall be 1’-6 for 5000 foot elevations and below. For footings located at elevations over 5,000 feet, the minimum top cover shall be 2’-6 to prevent frost heave.

## 10.7 Driven Piles

10.7.1 General

10.7.1.1 Application

Piling should be considered when spread footings cannot be founded on rock, or on competent soils at a reasonable cost. At locations where soil conditions would normally permit the use of spread footings but the potential exists for scour, liquefaction or lateral spreading, piles bearing on suitable materials below susceptible soils should be considered for use as a protection against these problems. Piles should also be considered where right-of-way or other space limitations would not allow the use of spread footings, or where removal of existing soil that is contaminated by hazardous materials for construction of shallow foundations is not desirable.

Piles should also be considered where an unacceptable amount of settlement of spread footings may occur.

Driven piles may be either H piles, pipe piles or prestressed concrete piles.

The geotechnical engineer is responsible for recommending when driven piles can be considered, the type of driven pile to be used, the service, strength or extreme event limit states capacity of the pile. The geotechnical engineer is also responsible for recommending the estimated pile tip elevation and any special requirements necessary to drive the piles. When steel piles are used, the corrosive life of the pile should be reported in the geotechnical report.

The bridge designer is responsible for ensuring that the axial capacity and the lateral capacity of the pile or pile group are not exceeded for any AASHTO LRFD limit states group loadings.

Bridge designers shall include the following information per abutment and pier foundation on the project plans:

- Total settlement which is used in the design of the driven pile based on the geotechnical foundation report.
- Total unfactored axial load at the top of each driven pile before increasing the axial load to account for redundancy or group efficiency effects.
- Total unfactored axial load at the top of each driven pile which is used in the design of the pile after increasing the axial load for redundancy or group efficiency effects.

## 10.8 DRILLED SHAFTS

### 10.8.1 General

During the preliminary design stage, the Bridge Engineer shall provide the Geotechnical Engineer with anticipated drilled shaft diameters for piers and abutments in addition to drilled shaft strength and service loads for abutments and piers. This information will allow the Geotechnical Engineer to determine the necessary drilling depth during the geotechnical investigation.

The geotechnical engineer shall develop the following two charts:

- Chart 1: Strength axial resistance, plotted as abscissa, versus depth of embedment for various shaft diameters, plotted as ordinate.

- Chart 2: Service axial resistance for a given vertical displacement of the shaft top, plotted as abscissa, versus depth of embedment for various shaft diameters, plotted as ordinate. Chart 2 is repeated depending on the considered displacement values.

The geotechnical engineer shall indicate on the charts the elevation along with the depth on the ordinate axis.

The bridge designer shall use Chart 1 to evaluate the strength limit state and Chart 2 to evaluate the service limit state. In the event that the design displacement differs from the values provided in Chart 2, the bridge designer shall develop Chart 3. This chart will display the developed axial resistance, on the ordinate axis, versus vertical displacement for a shaft of given diameter and depth of embedment, on the abscissa axis.

Chart 3 is different from Chart 2 in the sense that Chart 3 is developed only for a specific diameter and depth of embedment while Chart 2 is developed for a range of shaft diameters and depths of embedment.

The bridge designer shall design the drilled shafts based on the memorandums on the ADOT Bridge Group website, (Geotechnical Services LRFD Design Memorandums).

The following criteria shall be used in designing drilled shaft foundations:

- Drilled shafts shall be designed for limit states and resistance factors as specified in AASHTO LRFD Article 10.5.
- All applicable service limit state load combinations in AASHTO LRFD Table 3.4.1-1 shall be used for evaluating lateral displacement of drilled shafts.
- Where soil deposit in which shafts have been installed is subject to settlement, due to consolidation or otherwise, in relation to the shafts, down drag loads shall be considered in the design of the drilled shafts.
- Drilled shafts shall be spaced a minimum of three diameters measured center-to-center of the shafts unless the geotechnical engineer approves a lower center-to-center spacing.
- The minimum diameter of the drilled shafts shall be four feet, unless the geotechnical engineer approves smaller diameter of drilled shafts for a specific site.
- Due to constructability issues, the length of a drilled shaft shall be limited to 20 times its diameter.
- All drilled shafts, except for pedestrian bridges or light pole and sign post foundations, shall have 6 inches minimum clear cover of the reinforcements to the outside edge of the shaft.
- Vertical reinforcing shall be detailed to provide the minimum recommended spacing in AASHTO LRFD Article 5.10.3. In no case the spacing between vertical reinforcing shall be less than 4 ½ inches.
- Horizontal ties shall be spaced not less than 6 inches and not more than 12 inches.

- Drilled shaft caps connecting two or more drilled shafts shall be sized along the length of the cap to extend a minimum of 9 inches from the edge of each exterior shaft.
- Inspection tubes shall be installed inside the drilled shaft for gamma-gamma logging device or cross hole sonic logging as per the current ADOT Standard Specifications for Road and Bridge Construction or updated stored specification. The number and locations of the tubes shall be detailed in the project plans. The minimum number of inspection tubes shall be equal to the diameter of the drilled shaft, measured in feet, and rounded-up to the next whole integer, but not less than four. The inspection tubes shall be uniformly distributed along the inside circumference of the reinforcing steel cage.
- If collapsing material or intermittent large boulders are found during the geotechnical investigation, a test drilled shaft may be constructed as part of the investigation and the results included in the final bridge foundation report.
- Rock-Socketed Shaft: A shaft where its lower portion or its entire length is embedded into the rock strata. This type of drilled shaft requires special heavy duty drilling equipment. Where rock-socketed shafts require casing through the overburden soils, the socket diameter shall be at least 6.0 inch less than the inside diameter of the casing. For rock-socketed shafts not requiring casing through the overburden soils, the socket diameter may be equal to the shaft diameter through the soil. Unless otherwise specified by the geotechnical engineer, the minimum embedment into the rock strata shall be 10 feet. A separate pay item shall be set up to account for the rock socket.
- Bell Shaped shafts and Telescoping shafts are not preferred in Arizona. The use of these shaft types requires prior approval from Bridge Group.

10.8.1.1 Scope

All drilled shafts shall be constructed vertically. Battered drilled shafts are not allowed. The geotechnical engineer is responsible for recommending the minimum diameter of the shaft and for providing the necessary information for determining the minimum required embedment below a specified elevation to develop the required resistance to the design axial and lateral load. The geotechnical engineer is also responsible for determining the soil properties in each layer to be used in resisting lateral loads. In the Bridge Foundation Report, the geotechnical engineer shall specify a method of drilled shaft construction based on either dry or wet excavation. In the event of wet excavation, slurry, temporary casing, or permanent casing is usually recommended depending on the water table elevation and soil condition.

The axial and lateral capacity of the drilled shafts shall be reduced by ignoring the embedment within the specified scour depth as documented in the Bridge Hydraulics Report.

Bridge designers shall include the following information per drilled shaft on the project plans:

- Total settlement which is used in the design of the drilled shaft based on the geotechnical report.
- Total unfactored axial load at the top of the drilled shaft before increasing the axial load to account for redundancy or group efficiency effects.

- Total unfactored axial load at the top of the drilled shaft which is used in the design of the drilled shaft after increasing the axial load for redundancy or group efficiency effects.

10.8.1.4 Battered Shafts

Battered shafts shall not be used. Where increased lateral resistance is needed, consideration should be given to increasing the shaft diameter or increasing the number of shafts.

10.8.2 Service Limit State Design

10.8.2.2 Settlement

10.8.2.2.1 General

The settlement of a drilled shaft foundation involving either a single-drilled shaft or groups of drilled shafts shall not exceed the movement criteria selected in accordance with Article 10.5.2.2 of these guidelines.

If applicable, time-dependent and consolidation settlements, referred to as long-term settlements, of the drilled shaft foundation system shall also be determined by the geotechnical engineer. The bridge designer shall evaluate whether such settlements can be tolerated by the structure.