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.

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 total settlement of a foundation per 100 ft span to 0.5 in. Linear interpolation should be used for other span lengths. Higher total settlement limits may be used when the superstructure is adequately designed for such settlements. The designer shall also check other factors such as rideability and aesthetics. Any total settlement that is higher than 2.5 in, per 100 ft span, must be approved by the ADOT Bridge Group. Based on the ADOT Material Group’s recommendation, the differential settlement, which shall be used for the structural evaluation of any span, shall be the larger of the two total settlements of the foundations calculated at either end of that span assuming zero total settlement for the other foundation. The calculated settlements at each of the foundations are provided in the geotechnical report.

When the bridge is being built using a stage construction method, foundation settlements that do not induce forces in the superstructure may be subtracted from the total settlement of that foundation when calculating differential settlements. For bridges involving complex stage construction, the bridge designer should coordinate with the geotechnical engineer when calculating differential settlements.

The creep and the elasto-plastic characteristics of the soil surrounding the foundation, permit some moment relief for the columns. It is suggested that moments and shears due to prestressing could be reduced by 50%, and those due to thermal action could be reduced by 25%. These reductions are considered reasonable when applied to columns with a fixed connection to the foundation. When allowing limited foundation release using springs or some foundation translation, or if drilled shafts are being used, the prestress and thermal forces shall not be reduced. Therefore, reductions in the prestress and thermal forces must be used consistent with the analysis model.

10.5.5 Resistance Factors

10.5.5.2 Strength Limit States

10.5.5.2.4 Drilled Shafts

A bridge abutment or pier foundation consisting of two or more drilled shafts is considered as a redundant foundation.

10.6 SPREAD FOOTINGS

10.6.1 General Considerations

10.6.1.1 General

Provisions of this Article shall apply to design of isolated, continuous strip and combined footings for use in support of columns, walls and other substructure and superstructure elements.

In Arizona, the two most commonly used types of spread footings are:

- Isolated footings: which are used as individual support for the various parts of a substructure unit and may be stepped laterally.
- Combined footings: which are used to support more than one column for multi-column bents. They also could be used to support wall bents.

Spread footings shall be proportioned and designed such that the supporting soil or rock provides adequate nominal resistance, considering both the potential for adequate bearing strength and the potential for settlement, under all applicable limit states in accordance with the provisions of this Section.

Spread footings shall be proportioned and located to maintain stability under all applicable limit states, considering the potential for, but not necessarily limited to, overturning (eccentricity), sliding, uplift, overall stability and loss of lateral support.

When sound soil materials exist near the surface, shallow foundations in the form of spread footings are commonly used. For foundation units situated in a stream, spread footings may be used when they can be placed on non-erodible rock. Spread footings shall not be placed on embankment filled material unless approved by ADOT Bridge Group and ADOT Material Group.

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.

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 (in ksf) and the strength limit state factored net bearing resistance (in ksf) which are used in the design of the footing based on the geotechnical report.

10.6.1.2 Bearing Depth

The depth of footing shall be determined in consideration of the character of the foundation materials and the possibility of undermining. Footings at stream crossings shall be founded at a depth of at least 2.0 ft. below the maximum anticipated depth of scour as determined by the ADOT Bridge Hydraulics section and ADOT Geotechnical Section.

The bottom of spread footings shall be set at least to the depth recommended in the bridge foundation report. The minimum top cover over the top of the footings shall be 1’-6. For footings located at elevations over 5,000 feet, the minimum depth of embedment to the bottom of footings shall be 6’-0 to prevent frost heave.

Consideration shall be given to the use of either a geotextile or graded granular filter layer to reduce susceptibility to piping in rip rap or abutment backfill.

10.6.6 Spread Footing Design Considerations

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 inch 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 will design the spread footing based on the bearing resistance provided by the geotechnical engineer and the memorandum “Development of Factored Bearing Resistance Chart by the Geotechnical Engineer for use by a Bridge Engineer to size spread footings on soils based on service and strength limit states”.

This memorandum is available on the ADOT Material Group website:

http://www.azdot.gov/Highways/Materials/Geotech_Design/Policy.asp.

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.

Driven piles could be classified as follows:

- Battered Pile: A pile driven at an inclined angle to provide higher resistance to lateral loads.

- Friction Pile: A pile whose support capacity is derived principally from soil resistance mobilized along the side of the embedded pile.

- Point Bearing Pile: A pile whose support capacity is derived principally from the bearing resistance of the foundation material on which the pile tip rests.

- Combination Friction and Point Bearing Pile: A pile that derives its capacity from contribution of both friction resistance mobilized along the embedded pile and point bearing developed at the pile tip.

In Arizona, the following two types of piles are commonly used:

- Pipe Pile: 14 and 16 inch diameter steel pipes with 1/2 or 5/8 inch wall thickness are generally recommended for the shell. The pile is driven or vibrated down into the soil until the designed bearing capacity is reached. Then, the steel reinforcing cage is placed inside the shell. Finally, concrete is poured into the pipe. The bridge designer shall assume that the shell is not contributing to the structural capacity of the pile.

- Steel H-Pile: ASTM 709 grade 50 HP shape or as recommended by the geotechnical engineer shall be used. H-piles are generally classified as friction piles.

Bridge designers shall include the following information per abutment and pier foundation on the structure plan sheets:

- Total settlement which is used in the design of the driven pile based on the geotechnical 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.

10.7.2 Service Limit State Design

10.7.2.2 Tolerable Movements

The requirements of AASHTO LRFD Article 10.5.2.1 and Article 10.5.2.2 of these guidelines shall apply.

10.8 DRILLED SHAFTS

10.8.1 General

10.8.1.1 Scope

The provisions of this Section shall not be taken as applicable to drilled piles, e.g., augercast piles, installed with continuous flight augers that are concreted as the auger is being extracted.

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.

Drilled shafts installed under wet excavation conditions shall be inspected according to a method described in the ADOT Standard Specifications for Road and Bridge Construction or the project’s special provisions. Two commonly used methods are the gamma-gamma logging device and the cross-hole sonic logging survey.

The following types of drilled shafts are commonly used in Arizona:

- Prismatic Shaft: A shaft with constant diameter throughout its entire length.

- 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 Shaft: A shaft with a flared bell shape at its tip to increase the bearing area. This type of drilled shaft is more advantageous when stiff foundation material is documented which results in higher bearing capacity enabling the designer to reduce the drilled shaft length. The entire base area may be taken as effective in transferring the load only if appropriate provisions are included in the contract documents so that the bottom of the bell shaped drilled hole is cleaned and inspected prior to concrete placement. Due to the difficulty of properly cleaning the bottom of the hole, this type of drilled shaft is not a preferred alternative.

- Telescoping Shaft: A shaft with two or more segments of consecutively smaller diameters. In order to avoid using excessive steel casing for shoring purpose during drilled shaft construction when very loose foundation material is present, telescoping augering technique can be beneficial to accommodate varying soil conditions. The bridge designer should avoid using this type of drilled shaft due to the inherent difficulty of constructing it.

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

- 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

10.8.2.1 Tolerable Movements

The requirements of AASHTO LRFD Article 10.5.2.1 and Article 10.5.2.2 of these guidelines shall apply.

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.

10.8.5 Drilled Shafts Design Considerations

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.

Note: Since project plans must show the elevations, the geotechnical engineer should indicate 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 an additional Chart “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.

Note that 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 memorandum “Development of Drilled Shaft Axial Resistance Charts for use by Bridge Engineers”. This memorandum is available on the ADOT Material Group website:

http://www.azdot.gov/Highways/Materials/Geotech_Design/Policy.asp.

Unless otherwise specified in the bridge foundation report, 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.
- Due to the fact that boulders may be encountered during the drilling operation, 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.
- Drilled shafts of six feet or more in diameter or which may be constructed using slurry or wet method, shall have 6 inches minimum clear cover of the reinforcements to the outside edge of the shaft.
- Drilled shafts of less than six feet in diameter and which are constructed in dry soil, shall have at least 3 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.
- If wet excavation is anticipated for the drilling, inspection tubes shall be installed inside the drilled shaft for gamma-gamma logging device or cross hole sonic logging as per Special Provisions or current ADOT Standard Specifications for Road and Bridge Construction. 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.
- Confirmation shafts shall be designated in the bridge plan.
- 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.

10.10 GEOTECHNICAL REPORTS

10.10.1 General

Two geotechnical reports shall be prepared by the geotechnical engineer. The first one is a preliminary report that is used to start the foundation design resulting in stage II plans. The second one is the final geotechnical report which is used to document geotechnical parameters that are used in the final foundation design. The final geotechnical report shall be submitted part of stage II deliverables.

During the development of stage II plans, and especially while designing deep foundation elements, the bridge designer may discover the need for deeper borings than initially used in the preliminary geotechnical report. The bridge designer shall communicate this information to the geotechnical engineer so that the latter could base the final report on this additional data.

10.10.2 Preliminary Geotechnical Report

The preliminary geotechnical report shall contain the following:

- Introduction
- Site description
- Subsurface conditions
- Geomorphology of the waterway, if applicable
- Consideration of the effect of scour, if applicable
- Recommendation for test shafts, if necessary
- Soil parameters which are required for lateral and stability analysis of the foundation
- Foundation recommendations with force resistance charts such as axial and bearing as required for foundation design
- Boring log with general plan and elevation
- Laboratory test results

10.10.3 Final Geotechnical Report

The final geotechnical report shall contain the following additional items:

- Documentation of the test shaft results, if applicable
- Final foundation recommendations with force resistance charts such as axial and bearing as required for foundation design
- Special provisions, if necessary
- Foundation data sheets