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From: John Lawson
Manager, Geotechnical Design Section
Materials Group (068R)

Subject: Geotechnical Design Policy DS-2
Load Resistance Factor Design (LRFD)
Design of Drilled Shafts in Gravel and Gravelly Soils Exhibiting Drained Behavior

The AASHTO (2010) LRFD Bridge Design Specifications are mandatory for all federally funded projects. This attached policy presents procedures specifically for the design of drilled shafts in gravels and gravelly soils that exhibit drained behavior. Modifications to AASHTO (2010) have been outlined in the policy.

Personnel, both within ADOT and design consultants working on projects that require LRFD for substructures, shall follow the attached policy. The designer should contact the ADOT Materials Group for an updated version of this policy in the event any interim revisions are made to AASHTO (2010), or a new edition of AASHTO is issued.

Modified side load transfer curves for gravel and gravelly soils are presented in the policy for the design of drilled shafts. Also, criteria to define and procedures for determining gravels and gravelly soils are included in the policy.

The procedures for the design of drilled shafts in gravel and gravelly soils are given in the attached policy. If you have any questions regarding this bulletin, please contact Jim Wilson at 602-712-8081 or John Lawson at 602-712-8130.

REVISION LOG
ADOT Policy Memorandum: ADOT DS-2
Date of Original Issue: January 28, 2008

Interim Guidance – Design of Drilled Shafts in Gravels and Gravelly Soils Exhibiting Drained Behavior

Revision (Date)	Changes
1 (December 1, 2010)	1. As appropriate, update reference to AASHTO from AASHTO (2007) to AASHTO (2010). 2. Introduce a policy memorandum number (ADOT DS-2) on Page 1 to permit proper referencing of the memorandum in project reports and other policy memoranda. 3. On Page 4 of 6 change ARIZ 201, ASTM D2487 and ASTM D75 to ARIZ 201c, ASTM D2487-10 and ASTM D75/D75M-09, respectively to reflect the correct/latest designations. 4. On Page 5 of 6, in Section III-2 add "with the conditions for the maximum value of q_p noted in Article 10.8.3.5.2c." at the end of the paragraph. 5. On Page 6 of 6 include (1) references for ARIZ 201c, ASTM D75/75M-09, and ASTM D2487-10 testing standards, and (2) expanded citation for reference to Rollins *et al.*

Arizona Department of Transportation

Materials Group - Geotechnical Design Section

MEMORANDUM

To:	Date:
John Lawson, P.E., Manager, Geotechnical Design Section	**January 28, 2008** **December 1, 2010 (Revision 1)**
From:	**Subject: Interim Guidance[1] - Design of Drilled Shafts in Gravels and Gravelly Soils Exhibiting Drained Behavior**
Norman H. Wetz, P.E., Senior Geotechnical Engineer **James D. Wilson, P.E., Geotechnical Planning Engineer**	

ADOT POLICY MEMORANDUM: ADOT DS-2

This memorandum presents guidance specifically for the design of drilled shafts in gravels and gravelly soils that exhibit drained behavior. Interim guidance regarding both side resistance and tip resistance is provided. The criterion for "sands" is also presented to aid in a clear determination of gravels, gravelly soils, and sands within the overall framework of coarse-grained soils exhibiting drained behavior.

Figure 10.8.2.2.2-3 of AASHTO (2010), shown here as Figure 1, presents curves for normalized side load transfer versus normalized settlement for coarse-grained cohesionless soils in general. Specific curves for "gravel" are also shown in this figure. This memorandum presents curves that supersede the "gravel" curves in Figure 1 and outlines criteria for the design of drilled shafts in gravels and gravelly soils exhibiting drained behavior.

I. Modified Side Load Transfer Curves

The side load transfer curves for "gravel" in Figure 1 are the same as those in O'Neill and Reese (1999), who noted that these curves were developed from a limited database. For this reason there is no trend line shown for these data. A trend line is defined as the curve that provides the most probable fit to the available data. Subsequent to the publication by O'Neill and Reese in 1999, additional databases regarding side load transfer curves for gravels and gravelly soils have become available. ADOT evaluated these databases and, based on parametric studies, decided to replace the AASHTO "gravel" curves with the two sets of curves shown in Figures 2 and 3 for gravels and gravelly soils, respectively, which exhibit drained behavior.

The curves in Figures 2 and 3 were adapted from the normalized load versus displacement curves presented by Rollins *et al.* (2005). The word "ultimate" is used in Figures 2 and 3 in the caption on the ordinate to be consistent with the terminology used in AASHTO (2010) as shown in Figure 1. In LRFD terminology, the word "ultimate" is synonymous with "nominal."

[1] The reason this memorandum represents an "interim guidance" is because ADOT Materials Group will continue to evaluate latest load test data in gravelly soils and modify the guidance as necessary. Modifications may also be made in the event any interim revisions to AASHTO (2010) are issued or a new edition is issued.

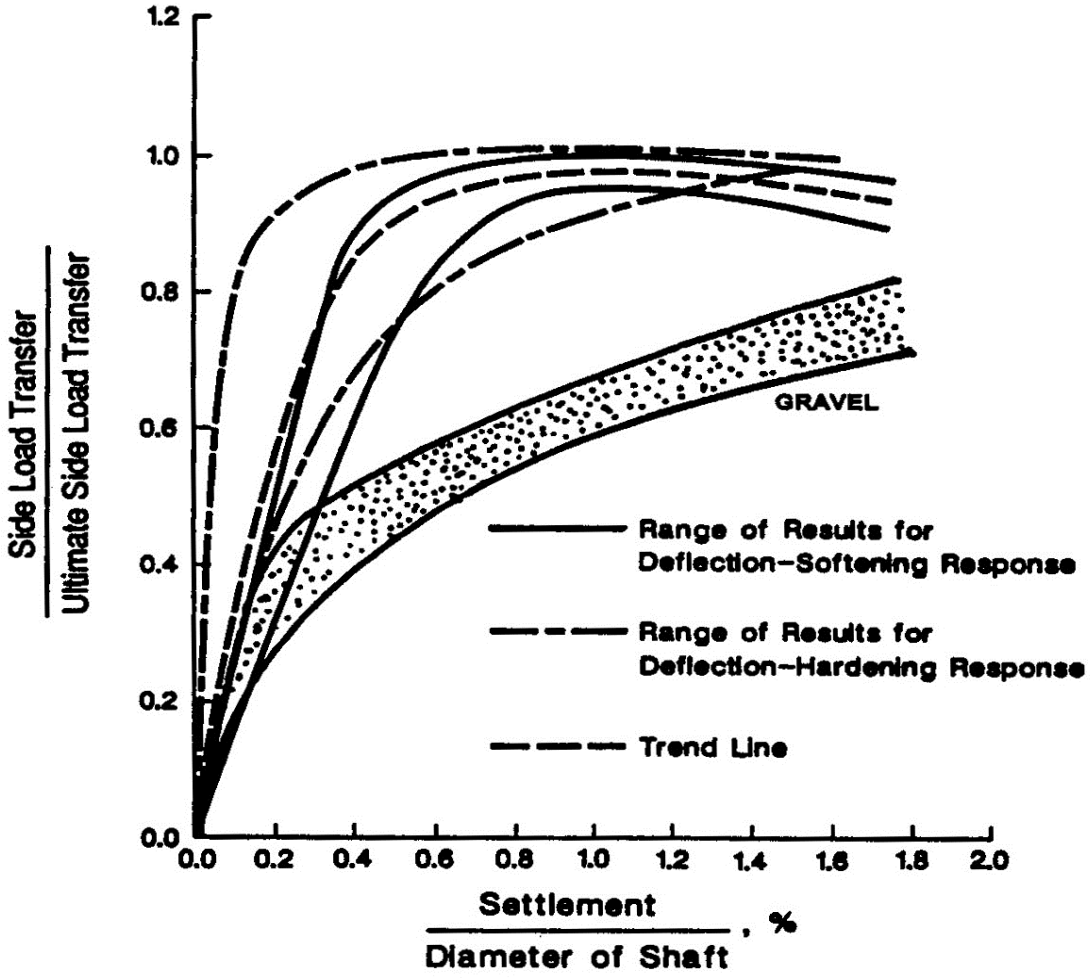

Figure 1: Normalized Side Load Transfer Curves for Drilled Shafts in Cohesionless Soils (Figure 10.8.2.2.2-3 of AASHTO (2010)).

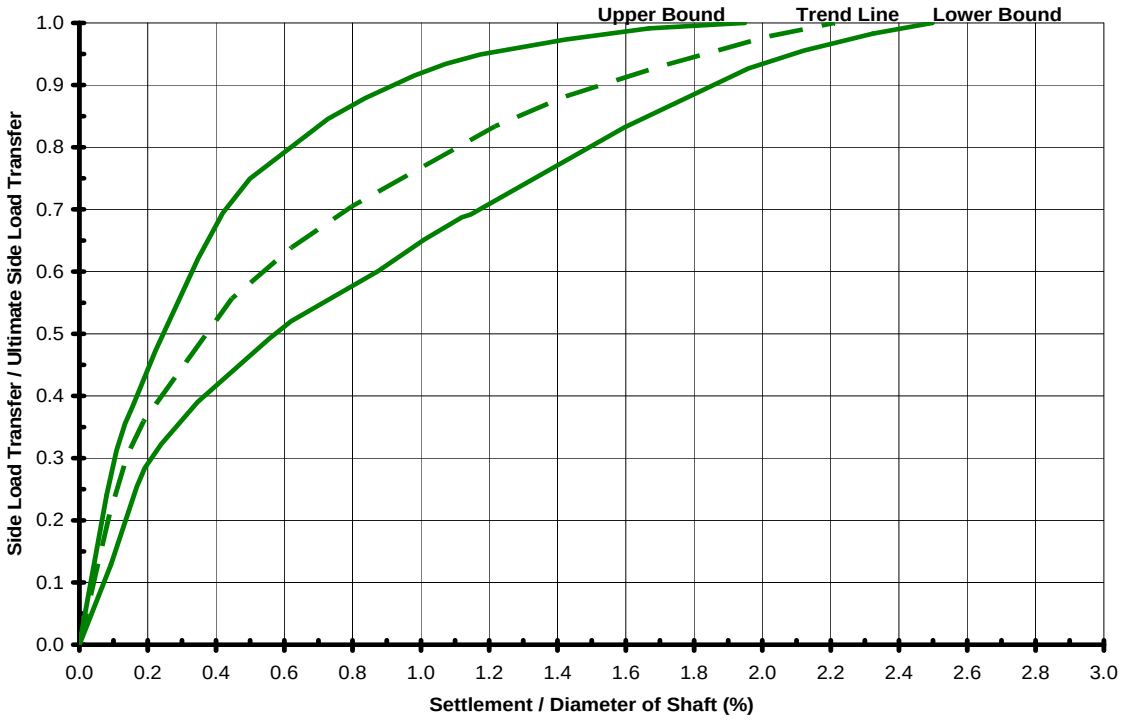

Figure 2: Side Load Transfer Curves for Gravels Exhibiting Drained Behavior (after Rollins, *et al.*, 2005)

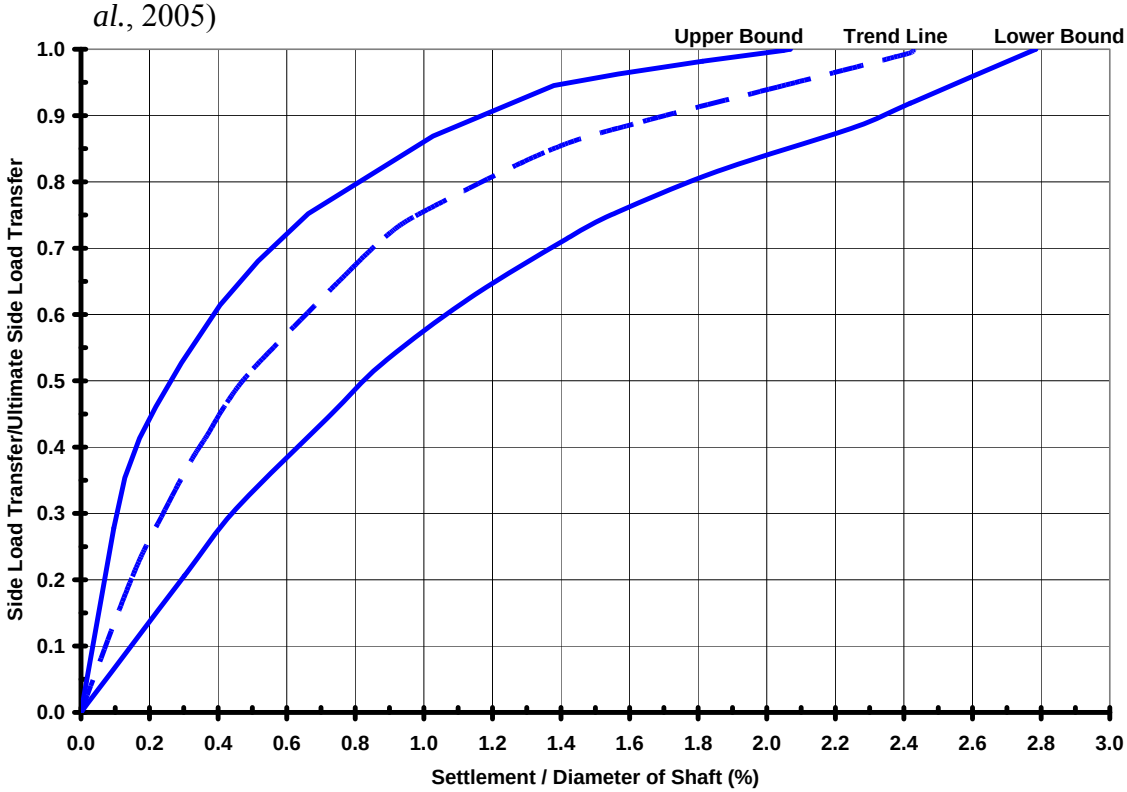

Figure 3: Side Load Transfer Curves for Gravelly Soils Exhibiting Drained Behavior (after Rollins, *et al.*, 2005).

II. Criteria for Use of Side Load Transfer Curves for Coarse-Grained Soils Exhibiting Drained Behavior

The following criteria shall be used to determine the appropriate side load transfer curves for coarse-grained soils exhibiting drained behavior (modified after Rollins, *et al.* 2005):

- Gravels: Greater than 50% of the coarse-grained soils is gravel size
  - Use trendline in Figure 2
- Gravelly soils: Between 15% to 50% of the coarse-grained soils is gravel size
  - Use trendline in Figure 3
- Sands: Less than 15% of the coarse-grained soils is gravel size
  - Use trendline in Figure 1

The definitions of coarse-grained soils, gravel size and sand size are as follows as per ASTM D2487-10:

- Coarse-grained soils: more than 50% of the total sample retained on No. 200 (0.0029") sieve. As per Unified Soil Classification System (USCS) in ASTM D2487-10, coarse-grained soils have designations GW, GP, GM, GC, SW, SP, SM, SC, GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SW-SC, SP-SM, SP-SC or SC-SM.
- Gravel size: No. 4 sieve (0.1875") to 3"
- Sand size: No. 200 sieve (0.0029") to No. 4 sieve (0.1875")

The presence of gravels and gravelly soils shall be documented based on laboratory grain size distribution curves rather than visual classification procedures. The size of the sample for laboratory testing shall be in accordance with ASTM D75/D75M-09. The laboratory grain size distribution tests shall be performed according to ARIZ 201c on samples retrieved from borings with a minimum diameter of 18-inches advanced with a discontinuous flight auger similar to drilled shaft soil augers. A continuous lithologic profile of the auger hole shall be documented to delineate the extents of the gravel and gravelly soils so that the appropriate design formulation can be used for different soil types. In any event, contact ADOT Materials Group for site-specific investigations requirements regarding location and frequency of the 18-inch diameter auger borings and the frequency of sampling and gradation testing from such borings for soil profiles containing gravels or gravelly soils. Depending on the geologic conditions for a specific project, the ADOT Materials Group may allow use of sonic drilling methods in lieu of 18-inch diameter auger borings.

In the event that the investigation techniques noted above cannot be provided, the geotechnical designer shall use the default recommendations in Figure 1 for coarse-grained soils exhibiting drained behavior.

III. SPT N_{60} Value Considerations

AASHTO (2010) suggests that a cohesionless soil deposit with $N_{60} > 50$ should be considered as an intermediate geomaterial (IGM) and analyzed accordingly. The analytical model for IGM in AASHTO (2010) was based on residual soils of the Piedmont province in southeast US. For the soil conditions in Arizona, the ADOT Materials Group recommends that coarse grained soils exhibiting drained behavior not be considered intermediate geomaterials (IGMs) as defined by AASHTO (2010). For such soils, the drilled shaft design shall be performed as outlined in Sections III.1 and III.2. When approved by ADOT Materials Group, these recommendations may be superseded by results of project- and site-specific load tests.

III.1 Side Resistance

- For gravels and gravelly soils as defined in Section II use Eq. 10.8.3.5.2b-1 of AASHTO (2010) and the β coefficient calculated by Eq. 10.8.3.5.2b-4 of AASHTO (2010) with trendlines in Figure 2 or 3 as appropriate.

- For sands as defined in Section II use the trendline in Figure 1 with Eq. 10.8.3.5.2b-1 of AASHTO (2010) and the β coefficient calculated by Eq. 10.8.3.5.2b-2 and Eq. 10.8.3.5.2b-3 of AASHTO (2010) as appropriate based on N_{60} value.

III.2 Tip Resistance

- For all coarse-grained soils as defined in Section II, use the trend line for the load transfer curves in Figure 10.8.2.2.2-4 of AASHTO (2010) with Eq. 10.8.3.5.2.c-1 of AASHTO (2010) with the conditions for the maximum value of q_p noted in Article 10.8.3.5.2c.

IV. Resistance Factors

For all coarse-grained soils as defined in Section II, the resistance factors for sands as specified in Table 10.5.5.2.4-1 of AASHTO (2010) shall be used.

V. Closing Comments

This memorandum contains interim guidance for the determination of side and tip resistance in coarse-grained soils exhibiting drained behavior only. Definitions for gravel, gravelly soils and sands are presented. For other soils and conditions (e.g., undrained or total stress behavior) follow the recommendations in AASHTO (2010).

The guidance in this memorandum will be revised by the Materials Group of ADOT as more load test data for such soils are collected. The geotechnical designer should contact the Materials Group for the latest guidance in this regard.

VII. References

AASHTO (2010). ***AASHTO LRFD Bridge Design Specifications***. 5th Edition. American Association of State Highway and Transportation Officials, Washington, D.C. (including latest errata and interims).

ARIZ 201c. ***Sieving of Coarse and Fine Graded Soils and Aggregates (An Arizona Method)***. ADOT Materials Testing Manual, http://www.azdot.gov/Highways/Materials/QA/QA_Manuals/Materials_Testing/SERIES200/PDF/Ariz201c.pdf.

ASTM D75/D75M–09. ***Standard Practice for Sampling Aggregates***, ASTM International, West Conshohocken, PA, DOI: 10.1520/D0075_D0075M-09, www.astm.org.

ASTM D2487–10***. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System),*** ASTM International, West Conshohocken, PA, DOI: 10.1520/D2487-10, www.astm.org.

O'Neill, M. W. and L. C. Reese (1999). ***Drilled Shafts: Construction Procedures and Design Methods,*** FHWA-IF-99-025, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Rollins, K. M., Clayton, R. J., Mikesell, R. C. and Blaise, B. C. (2005). "Drilled Shaft Friction in Gravelly Soils," ***Journal of Geotechnical and Geoenvironmental Engineering***, Vol. 131, No. 8, pp. 987-1003, American Society of Civil Engineers, Reston, VA.