Bridge and Structures Office
Washington State
Department of Transportation

Design Memorandum

TO: All Design Section Staff

FROM: Bijan Khaleghi
DATE: June 28, 2010
SUBJECT: Bearing Resistance of Shaft Groups

The group reduction factors for bearing resistance of shafts for the strength and extreme event limit states shall be taken as shown in Table 1. These reduction factors presume that good shaft installation practices are used to minimize or eliminate the relaxation of the soil between shafts and caving. If this cannot be adequately controlled due to difficult soil conditions or for other reasons, lower group reduction factors should be considered, or steps should be taken during and after shaft construction to restore the soil to its original condition.

Table 1. Group reduction factors for bearing resistance of shafts

Soil Type	Shaft Group Configuration	Shaft Center-to-Center Spacing	Special Conditions	Group Reduction factor, η
Cohesionless (e.g., sands and gravels)	Single row	2D		0.90
		3D or more		1.0
	Multiple row	2.5D		0.67
		3D		0.80
		4D or more		1.0
	Single and multiple rows	2D or more	Shaft group cap in intimate contact with ground consisting of medium dense or denser soil	1.0
	Single and multiple rows	2D or more	Full depth casing is used and augering ahead of the casing is not allowed, or pressure grouting is used along the shaft sides to restore lateral stress losses caused by shaft installation, and the shaft tip is pressure grouted	1.0
Cohesive (Clays, clayey sands, and glacially overridden well graded soils such as glacial till)	Single or multiple rows	2D or more		1.0

These recommendations apply to both strength and extreme event limit states. For the service limit state the influence of the group on settlement as required in the AASHTO specifications and the WSDOT GDM are still applicable.

This memorandum applies to all new and ongoing WSDOT in-house or consultant designed bridges regardless of the contracting method.

Background:

Article 10.8.3.6.1 in the AASHTO LRFD Bridge Design Specifications sates that "reduction in resistance from group effects shall be evaluated." These specifications further state in Article C10.8.3.6.1 that "in addition to overlap effects, drilling of a hole for a shaft less than three shaft diameters from an existing shaft reduces the effective stresses against both the side and base of the existing shaft. As a result, the capacities of individual drilled shafts within a group tend to be less than the corresponding capacities of isolated shafts. However, if casing is advanced in front of the excavation heading, this reduction need not be made."

In Article 10.8.3.6.3, the AASHTO Specifications further state that "for shafts in cohesionless soil, regardless of cap contact with the ground, the individual nominal resistance of each shaft should be reduced by a factor η for an isolated shaft taken as:

- η = 0.65 for a center-to-center spacing of 2.5 diameters,
- η = 1.0 for a center-to-center spacing of 4.0 diameters or more.

For intermediate spacings, the value of η may be determined by linear interpolation."

The commentary to that article (C10.8.3.6.3) further states that "the bearing resistance of drilled shaft groups in sand is less than the sum of the individual shafts due to overlap of shear zones in the soil between adjacent shafts and loosening of the soil during construction. The recommended reduction factors in Article 10.8.3.6.3 are based in part on theoretical considerations and on limited load test results. See O'Neill and Reese (*1999*) for additional details and a summary of group load test results. It should be noted that most of the available group load test results were obtained for sands above the water table and for relatively small groups, e.g., groups of 3 to 9 shafts. For larger shaft groups, or for shaft groups of any size below the water table, more conservative values of η should be considered."

A review of the background for these design specifications on shaft groups reveals that these specified group reduction factors are based on a recommendation by Barker, et al. (1991) in NCHRP Report 343, which formed the basis of the first edition of the AASHTO LRFD Bridge Design Specifications published in 1994, specifically Section 10. Barker, et al.'s recommendation was based on the recommendation in the FHWA's NHI drilled shaft course manual produced in 1988 (Reese and O'Neill, 1988, *Drilled Shafts*, FHWA-HI-88-042). This manual based its recommendation on shaft group reduction factors for bearing on an ASCE paper by G. G. Meyerhof published in 1976 ("Bearing Capacity and Settlement of Pile Foundations," 1976, ASCE Geotechnical Journal, Vol. 102, No. GT3, pp. 196-228). The Meyerhof paper recommendation is based on theoretical shaft tip stress bulb overlap considerations (the paper indicated that this could reduce the tip resistance by 50% at a shaft spacing of 3 diameters, with some reduction in side resistance as well), and on a bored pile group load test reported in a paper published in German in 1933. The paper went on to recommend a total reduction factor η of 0.67 at a spacing of 3 diameters.

Since that time, a compilation of research on the subject of group reduction factors for drilled shaft foundations was published in the updated FHWA Drilled Shaft Course manual (O'Neill and Reese, 1999, *Drilled Shafts: Construction Procedures and Design Methods*, FHWA-IF-99-025) and again in the latest update to the FHWA Drilled Shaft Course manual (Brown, et al., 2010, *Drilled Shafts: Construction Procedures and LRFD Design Methods*, FHWA-NHI-10-016). Both the 1999 FHWA manual and the 2010 FHWA manual state that the AASHTO shaft group reduction factors are likely conservative and should be considered to be a lower bound value. The 2010 manual also states that in general, based on small scale field tests around the world in cohesionless soils (see the FHWA manual for details), a group reduction factor,η, of 1.0 should be expected for shaft spacings of 3D to 4D or more. Furthermore, both manuals recommend that the compilation of shaft group research results compiled in the manuals be considered when establishing a group reduction factor to use for design.

The group reduction factor shown in Table 1 are based on the review of the available information on bearing resistance and efficiency of shaft groups, the lowest group reduction factor provided in the current AASHTO Specifications (0.67) should be considered to be a lower bound value, and the group reduction factors provided in Table 1 should be used.

If you have any questions regarding these issues, please contact Tony Allen at 709-5450 or Bijan Khaleghi at 705-7181.

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