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Capacity Confusions in 2007

Frank Rausche, Garland Likins, Pat Hannigan

In an article published in the GRL Newsletter Number 24, of November 1994[1], Dr. George Goble presented a typical experience of a foundation testing engineer who comes to a construction site and is instructed to test a 100 ton driven pile. The engineer asks whether 100 tons is the design load or the required ultimate capacity, but cannot get a clear answer. The article exemplifies the sometimes hilarious, sometimes embarrassing and sometimes even outright antagonistic exchanges that arise from this lack of understanding of the basics of foundation design.

Since 1994, some progress has been made towards a better understanding of these basics, due to the efforts of the Federal Highway Administration. The FHWA, which under the leadership of Jerry DiMaggio, sponsored the updating, dissemination and teaching of material contained in Design and Construction of Driven Pile Foundations (Hannigan et al, 2006). Today most foundation professionals use **Allowable Stress Design** with the required ultimate capacity equal to the design load times a factor of safety (FS). In the United States, FS = 2.0 for buildings (as per International Building Code 2006) regardless of load testing method; for highway bridges the factor of safety varies with the capacity verification method (Hannigan, 2006, p. 9-14).

Starting in October of 2007, American Association of State Highway Transportation Officials Interim Specifications (AASHTO, 2006) will require **Load and Resistance Factor Design** (LRFD) for highway bridge design. When using LRFD, the structural engineer will calculate a Factored Load which, depending on its dead load, live load and other load components, will be multiplied by associated **Load Factors** (e.g., 1.25 for dead load and 1.75 for live load).

The geotechnical engineer will estimate the foundation depth for a **Required Nominal Resistance** (AASHTO's equivalent term for "Ultimate Capacity") that has to exceed **Factored Load** divided by a **Resistance Factor.** The specified **Resistance Factors** vary with the capacity verification method since each method (static or dynamic test, wave equation or dynamic formula) has a different reliability and may also yield a method-specific capacity value. Also, capacity increase with time (called "set-up") is often the cause for differences between different tests. To obtain the Nominal Resistance of dynamic tests conducted with a Pile Driving Analyzer®, the records must be evaluated by signal matching (e.g., by CAPWAP®). A wave equation bearing graph together with an observed blow count yields the wave equation specific Nominal Resistance.

Shown below are **Resistance Factors, φ,** of the current 2006 AASHTO Interim Specifications. The resulting **Global Factors of Safety, GFS,** were calculated for best case scenario for sites with low variability and 5 or more driven piles in a pier (highly redundant foundation), assuming a 70/30 dead load / live load ratio for a combined average **Load Factor** of 1.4. Current practice AASHTO factors of safety, **FS,** (Hannigan, 2006, p. 9-14) are shown for comparison.

Capacity Verification Method	φ AASHTO 2007	GFS AASHTO 2007 Example	Current Practice FS
1 static test	0.80	1.4/0.80 = 1.75	2.00
4 dynamic tests	0.65	1.4/0.65 = 2.15	2.25
Wave equation	0.40	1.4/0.40 = 3.50	2.75

In this example, static and dynamic testing global factors of safety differ by -12.5 and -4.5% from current practice. However, the resulting GFS for wave equation exceeds current practice by a surprising 27%. Even higher factors of safety for all methods will result when reduced redundancy and higher site variability are considered under AASHTO 2006 Interim. The current AASHTO 2006 Design Interim is only a recommendation to the various State Departments of Transportation and changes to these factors are expected as experience is gained with time.

Let us hope that the understanding of the basics of foundation design will continue to improve in the future. Ideally, when a foundation testing engineer will arrive on site, the designer will have clearly spelled out the Required Nominal Resistance. Let us also hope that job specifications will require re-strike testing for soils with set-up potential and that, when many foundation elements are tested, a slightly low capacity of a single pile can be offset by the higher capacity of others. Then the practice of the tester need not differ much from what we are doing today and the potential advantages of the LRFD method can be realized.

AASHTO Bridge Design Specifications, 2006 Interim Revision, American Association of State Highway Transportation Officials, Washington DC.

Hannigan, P., Goble, G., Likins, G., and Rausche, F., 2006. Design and Construction of Driven Pile Foundations, Volumes I and II. National Highway Institute, Federal Highway Administration, US Department of Transportation, Washington, D.C.. Previously published in 1997.

International Building Code 2006, International Code Council, Inc., Leesburg, Virginia, USA

[1] *The article is available at www.pile.com/newsletter.*