No. 0092-10-09 Wisconsin Highway Research Program • http://wisdotresearch.wi.gov/project?id=79 August 2013

PUTTING RESEARCH TO WORK
BRIEF

Improving Agreement Between Static Method and Dynamic Formula for Driven Cast-In-Place Piles

Many transportation facility structures in Wisconsin are founded on driven round, closed-end, steel, pipe piles. The piles are driven to capacity and then filled with concrete. The Wisconsin Department of Transportation (WisDOT) has designed and driven many of these pipe piles using the Load Factor Design (LFD) methodology. WisDOT's experience indicates that design pile length estimations have generally been fairly accurate when compared to driven pile lengths. Driven lengths have been determined based on penetration resistance measured in the field using the Wisconsin-modified Engineering News (EN) driving formula, as described in Section 508 of the Standard Specifications for Highway and Structure Construction.

What is the problem?

WisDOT no longer uses the EN formula nor the LFD design methodologies and now designs structural transportation facilities using AASHTO Load and Resistance Factor Design (LRFD) methodologies and the FHWA-modified Gates formula. AASHTO and FHWA both recommend that this new methodology be calibrated to local conditions and past experience.

Research objective

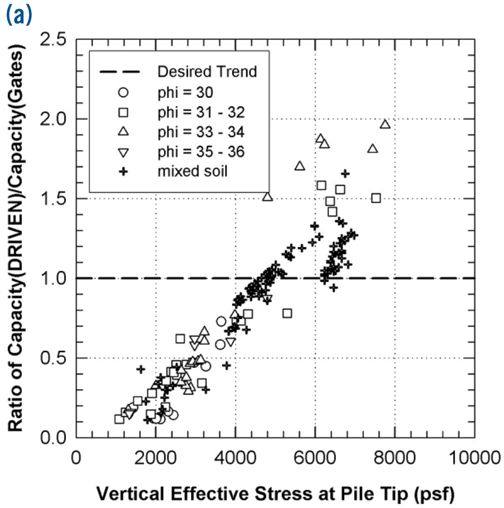
These were the objectives of this research project:

- Provide needed data and analyses to help WisDOT determine the effects of changing to the AASHTO LRFD methodology and also changing from the modified-EN pile installation method to the modified Gates or Washington State method.
- Provide data and recommendations on appropriate modifications to the AASHTO suggested design factors used in LRFD, based on local conditions and past experience.
- Compare, quantify and improve the agreement between as-designed and as-driven pile lengths.

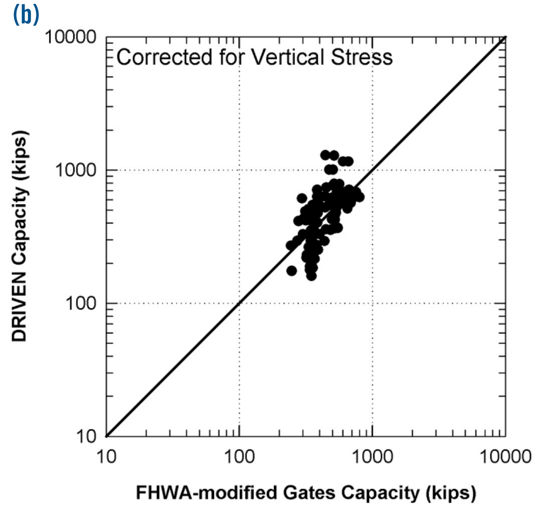
Investigator

James H. Long
Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign
jhlong@illinois.edu

(a)



(b)



(a) Effect of soil strength on ratio of estimated pile capacity using DRIVEN (with 36 degree limit) to the capacity using FHWA-modified Gates versus effective vertical stress.

(b) Estimated capacity using DRIVEN with correction factor for vertical effective stress and a conditional limit on friction angle versus the FHWA-modified Gates.

Methodology

One hundred eighty-two cases were collected, interpreted and analyzed in which driven cast-in-place (CIP) piles were used as foundation elements for bridge structures. For each case, the soil boring logs and the geotechnical reports were reviewed to develop a soil profile. Construction records for pile driving were collected and recorded to determine the pile hammer characteristics and the driving behavior of the pile during installation.

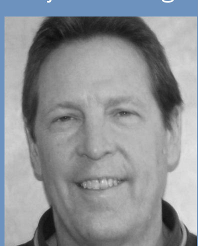
Axial capacities for all 182 piling cases were determined using a static method computer program (DRIVEN), two dynamic formulae (EN formula, FHWA-modified Gates), and wave equation analysis (WEAP) to determine the agreement between these methods. While all four estimates were determined for each case, particular emphasis was placed on the two methods commonly used by WisDOT, DRIVEN and FHWA-modified Gates. In using DRIVEN, Tomlinson's recommendations were selected for the relationship between unit side soil strength in fine-grained soil. Nordlund/Thurman methods were selected for unit side resistance and end bearing in coarse-grained soil.

Results

The researchers achieved the following results:

- DRIVEN exhibits a mild tendency to overestimate the length of pile penetration needed to reach capacity as determined with Gates. The tendency to overestimate length is most significant for the shorter pile. DRIVEN tends to underestimate pile penetration requirements for the longer piles compared to estimates using Gates.
- The average ratio of the pile capacity predicted with DRIVEN to that with FHWA-modified Gates was 1.35 with a coefficient of variation equal to 0.98 which corresponds to poor agreement. The pile capacity estimates using the Gates method are greater than estimates from DRIVEN up to about 600 kips, and then the Gates method predicts less capacity than DRIVEN. The same poor agreement exists between EN formula and DRIVEN and between WEAP and DRIVEN. However, there is good agreement between capacities estimated from dynamic methods, i.e., between EN formula and FHWA-modified Gates and between WEAP and FHWA-modified Gates.
- The most effective factors influencing the agreement between predictions made by DRIVEN and FHWA-modified Gates were the effective stress at the tip of the pile, the friction angle for coarse-grained soils, and whether the load was carried in side resistance or end bearing.
- The correction factors were proposed to correct the static method for overburden stress at the tip of the pile with the conditional limits for friction angle. The developed correction factors were very successful in reducing the scatter between capacity estimates from DRIVEN and FHWA-modified Gates. The average of the ratio of capacity predicted with DRIVEN to that predicted with FHWA-modified Gates for the 182 cases was determined to have a mean of 1.06 and a coefficient of variation of 0.28.
- A review of all the cases with the corrected DRIVEN indicated that soil profiles with Standard Penetration Test values greater than 80 would be better represented in DRIVEN by allowing friction angles to be as high as 40 degrees.

Project Manager



Jeffrey Horsfall
WisDOT
jeffrey.horsfall@dot.wi.gov

Recommendations

The researchers recommended the following steps to correct the static methods for effective stress at the tip of the pile and the limits for friction angles.

1) Conditionally limit the friction angle to a maximum of 36 degrees (if the Standard Penetration Test values exceed 80 bpf, then friction angles up to 40 degrees can be used).
2) Apply a correction factor to the side capacity (Q_{side}) as follows:

   $Q_{side\ corr}=Q_{side}/CF_{side}$ where, CF_{side} is determined as
   $CF_{side}=0.2 \leq -0.4615+1.4615\sigma'_{v\ tip}/4750 \leq 1.2$ where, $\sigma'_{v\ tip}$
   is the vertical effective stress (psf) at the tip of the pile, and

3) Apply a correction factor for end bearing (Q_{end}) as follows:

   $Q_{end\ corr}=Q_{end}/CF_{end}$ where, CF_{end} is determined as $CF_{end}=0.2 \leq -0.185+1.185\sigma'_{v\ tip}/4750 \leq 1.2$

This brief summarizes Project 0092-10-09,
"Comparison of LRFD and LFD Cast-In-Place Pile Design and Construction Methods"
Wisconsin Highway Research Program (WHRP) http://wisdotresearch.wi.gov/whrp