COMPUTER-BASED WAVE EQUATION ANALYSIS OF PILE DRIVEABILITY

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Abstract

A novel evaluation of pile driveability using the wave equation analysis is presented. Required analysis soil input is quite different from conventional type analysis information and more of the type traditionally used by geotechnical engineers. The soil resistance model considers soil layering and strength sensitivity to pile driving. Analysis results include computed parameters as a function of pile penetration depth.

Introduction

In the context of foundation engineering, the term Wave Equation Analysis refers to computer programs that simulate the dynamics of pile driving according to one-dimensional elastic wave propagation principles. Practical application of the wave equation to rationally analyze the pile driving problem was only possible after the advent of digital computers (Smith 1960, Goble and Rausche 1976, and Rausche et al. 1994).

A wave equation pile driveability analysis is performed to evaluate the ability of the proposed hammer and driving system to properly install the pile into the ground to required depth (and hence static load carrying capacity) in a timely manner and without the pile being subjected to damaging driving stresses. Traditionally, analysis results include computed pile driving stresses, energy transferred to the pile, and blow count, each for an assumed pile capacity. Usually a number of capacity values are analyzed at a constant pile penetration depth and the results

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shown in a plot known as a "Bearing Graph". However, for a true driveability analysis, capacity, blow count and pile stresses should be computed as a function of pile penetration. This paper presents a summary describing the new driveability approach incorporated into the GRLWEAP^{TM} program (Goble Rausche Likins and Associates, Inc. 1991).

New Pile Driveability Analysis Approach

With a conventional wave equation analysis, it is possible to obtain pile driving stresses and blow count versus pile penetration depth only by: (A) performing several analyses each with its own penetration and soil information, or (B) performing an analysis with a range of capacities at final depth and assuming that it would roughly approximate individual analyses at various depths. Method (A) is cumbersome and time consuming. Method (B) is unsatisfactory. The GRLWEAP program's "Blow Count versus Depth" or "Driveability Option" offers a novel approach to pile driveability analysis. Input parameters for the hammer, driving system and pile are the same as in a conventional analysis. Although the soil resistance model is the same, soil input parameters, however, are different from conventional type analysis. The approach allows for considerations of soil layering and strength sensitivity to pile driving. Since resistance values obtained by static analysis represent soil strength before, or long after pile installation, it is necessary to estimate the soil resistance during driving for a meaningful driveability analysis.

Starting with a depth of zero, the user may specify the soil properties at up to 99 separate depths. Soil information input consists of: unit shaft resistance and unit end bearing from traditional static analysis methods along with skin and toe quakes, skin and toe damping, and a "soil sensitivity" factor. This sensitivity factor is used to calculate the shaft resistance during driving from the full static friction considering each soil layer's strength gain/loss potential. The value of this soil sensitivity factor is greatest (e.g., equal to one) for the soil with the greatest friction loss and zero for soils with no strength loss at all. Utilization of several gain/loss and sensitivity factors is very useful in assessing pile driveability as a function of soil behavior during driving, or soil set-up due to interruptions in installation. The case study discussed below illustrates the use of the soil sensitivity factor.

Next, the user can input up to 50 pile penetration depths for analysis. At each depth, the following information may be specified: fuel setting for diesel hammers, ram stroke for external combustion hammers, hammer efficiency, and pile cushion stiffness and coefficient of restitution. Up to 10 analyses (depending on the number of loss/gain factors entered) are performed at each depth. Analysis results are presented in numeric and graph forms and include: calculated pile capacity, blow count, pile driving stresses (tension and compression), transferred energy, open end diesel hammer stroke and other variables as a function of pile penetration depth; in addition to anticipated total number of hammer blows and driving time.

Case Study

Situation: A 500-mm square, 40 m long prestressed concrete pile is to be driven to a capacity of 3500 kN. Allowable pile driving stresses are 24 and 9 MPa for compression and tension, respectively. A single acting air hammer having a ram weight of 53.4 kN with two fixed possible strokes (0.9 and 1.5 m) is to be used. Pile top cushion consists of 250 mm of plywood. Subsurface conditions are as follows: From ground level to a depth of 12.5 m (Layer I), sandy silts with calculated shaft and toe resistances linearly increasing to 30 and 4500 kPa, respectively; from 12.5 to 30.5 m (Layer II) a clay layer with constant 25 kPa shaft friction and 50 kPa end bearing unit values; the bearing layer (Layer III) consists of very dense sand with unit friction increasing from 100 to 140 kPa and unit end bearing increasing from 4500 to 8500 kPa at a depth of 33 m. It is assumed that Layers I, II, and III would temporarily lose a 1/3, 1/2 and 1/5 of their strength, respectively during pile driving. The pile should reach capacity at a penetration of 32.5 m. Can the pile be safely (i.e., without damage) and efficiently (i.e., without high blow counts) driven with this hammer to the required depth (i.e., capacity)? What are the anticipated final blow count and total driving time?

Solution: The Blow Count vs. Penetration Option in GRLWEAP™ was used. Hammer, driving system, and pile information were standard analysis input. Having established the lowest loss/gain factor (0.5), the clay layer's sensitivity was set to 1.0. The sensitivity of the silt and sand layers were then computed to be 0.67 and 0.4, respectively considering their respective loss/gain factors. The analysis is performed with a short hammer stroke until the sand (Layer III) is reached after which the stroke is increased to full value. To represent the increased cushion stiffness during installation, a stiffness multiplier of 1.2 was used towards the end. An analysis was performed at each 1 m depth increment to a depth of 31 m where it was changed to 0.5 m increments in the bearing layer.

Results: Analysis results including: pile resistance during driving, blow count, pile compression stress, pile tension stress, transferred energy (i.e., enthru) and hammer blow rate as a function of pile penetration depth are shown in Figure 1. Analysis indicates that maximum pile stresses throughout the driving process were less than allowable values. At a depth of 32.5 m, anticipated blow counts would be 247 blows per meter. Total driving time is estimated at 31 minutes.

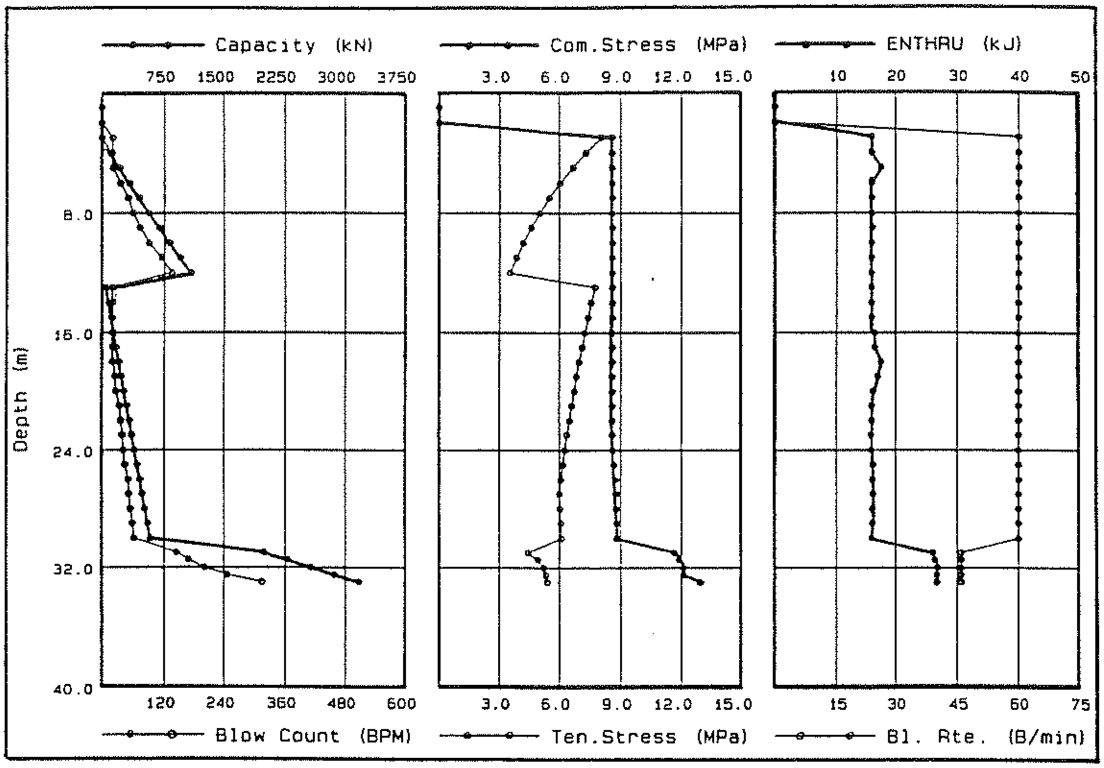

Figure 1: Driveability analysis results

Summary

Pile driveability evaluations using conventional wave equation analysis is cumbersome and time consuming. The novel approach incorporated into the GRLWEAP^{TM} program offers a rational, practical and accurate method for pile driveability analysis. Soil layering and strength sensitivity can be considered. Analysis results include computed parameters as a function of pile penetration depth.

References

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