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ENSOFT NEWSLETTER
Summer 2008

Advanced Analyses of Retaining Walls — PYWALL v3

The theoretical concepts used in the *PYWALL* software extend beyond the conventional method of analysis and design of flexible retaining walls based on limit-equilibrium theory. As a difference to conventional pratice, the *PYWALL* method includes the effects of soil-structure interaction.

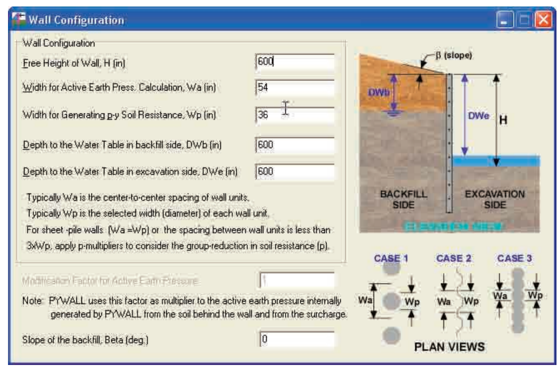
Modern methods of analyses of the behavior of retaining structures consider realistic soil conditions and relevant details of the structural system. Therefore, a rational method of analysis and design must include the nonlinear soil-resistance-displacement relationships, pile spacings, penetration depths and structural properties. *PYWALL* considers soil-structure interaction by using a beam-column model and can analyze the behavior of a flexible retaining wall or soldier-pile wall with or without tiebacks or bracing systems.

Other features and benefits of the *PYWALL* program are outlined below:

- Displacement or rotational restraints with nonlinear properties may be specified at multiple points along the wall to simulate bracings or tiebacks.
- The program can automatically generate active-earth pressures or the user may specify any type of distributed load as active pressure.
- The program provides graphs of wall deflection versus depth, shear force versus depth, bending moment versus depth, and the forces on any strut or tieback.

Some of the new features introduced with *PYWALL v3.0* are the following:

- Introduction of option to perform computation models of staged construction. This is a very convenient tool to study and to compare the predicted deflection, bending moment, and shear at different stages of construction based on a simplified approach.
- Option to conduct short-term and long-term analyses. Users can now define two sets of soil properties for short and long-term analyses to quickly evaluate and compare the different responses of the modeled wall.
- New *p-y* curve criteria for Weak Rock is added to existing criteria for Soft Clay, Stiff Clay with and without Free Water, Sand, Silt (c-ϕ) and Strong Rock (Vuggy Limestone).
- New interface reflecting improvements to facilitate data input and to reduce the learning curve of the program.■

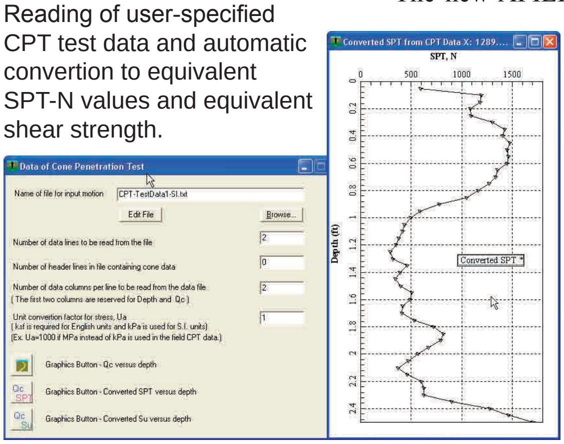


Axial Capacity of Driven Piles — APILE Plus v5

The APILE software is used to compute the axial capacity, as a function of depth, of a driven pile in clay, sand, or mixed-soil profiles.

The new APILE Plus v5 (Offshore Version) introduces two new computational methods: (i) the Norwegian Geotechnical Institute (NGI) method and (ii) the Imperial College Pile method (ICP also referred as the Marine Technology Directorate or MTD method). Both new methods are based on data that APILE Plus v5 can read automatically from outputs of Cone Penetration Tests (CPT).

Reading of user-specified CPT test data and automatic convertion to equivalent SPT-N values and equivalent shear strength.



In addition to the two new methods, APILE continues to offer computations based on: API-RP2A criteria, U.S. Army Corps of Engineers (USACE) method, U.S. Federal Highway Administration (FHWA) method, the Lambda-Method and any set of values specified by the user for load transfer in side resistance and end bearing as a function of depth.

In Version 5 users may enter a variation of cross-sectional area as a function of depth. This new feature is useful for tapered piles or for long pipe piles having sections with different wall thicknesses. Another new option added in APILE Plus v5 is the ability to perform computations for uplift loads.

With the recent wide usage of "CPT" tests, APILE can now read the CPT test data and then automatically convert to equivalent SPT-N values and equivalent shear strength.■

Technical Paper:
Comments on Methods of Analysis of Piles Under Lateral Loading©
by Lymon C. Reese

Introduction

Two methods are currently being used for the analysis of laterally loaded deep foundations: the method of load-transfer equations and the finite-element method. The finite-element method in this area has had limited use to date, but its use in a wide variety of geotechnical applications has been increased in recent years due to advances in computational power and capacity. The method of load-transfer equations is in common use by practicing engineers worldwide. The advantages and disadvantages of the two methods are discussed briefly in the following paragraphs.

The Finite Element Method

The author of this article became fascinated with the power of the finite-element method (FEM) during almost 40 years of teaching in the College of Engineering at The University of Texas. About mid-career in teaching and research in geotechnical engineering at Texas, a formal course in the FEM was taught, five dissertations were supervised, and eight articles were published in technical journals. The efforts made useful contributions to geotechnical engineering, but the author's efforts using the FEM to characterize nonlinear soils ceased about 35 years ago due to the difficulty of formulating nonlinear constitutive relationships for soil under a variety of loadings. Instead, the author pursued research that concentrated on field measurements of the behavior of full-scale foundations. The results of this original work continue to be of major value to researchers working today.

Since the author's early efforts using finite elements, substantial development of finite element analysis software and hardware has been accomplished. Today, modern finite element software normally have sophisticated tools to model and create three-dimension meshes, have multiple types of implicit and explicit solvers, and have the ability to solve problems exceeding 10 million degrees of freedom. The power of modern finite element analysis is truly impressive and the author and his colleagues at Ensoft, Inc. have used the method extensively and successfully on selected consulting projects. For example, the settlement of 28 closely spaced piled raft foundations at a manufacturing plant were predicted using three-dimensional finite element analysis and in another case, a pad-eye connection for anchoring a floating offshore structure was analyzed successfully.

The key in obtaining useful solutions using the finite element method is characterizing the material properties accurately. Even with such restrictions, some interesting problems can be solved. For a problem involving the response of a soil to loading, nonlinear constitutive relationships can be derived from the results of triaxial tests in the laboratory. Experience has found that when using these nonlinear constitutive relationships, several hours of time are required for convergence to a solution for a given set of loadings, employing the fastest available desktop computer. Thus, the ability to do trial runs to investigate the variations in meshing and selection of appropriate boundary conditions is practically impossible given the constraints of normal consulting practices.

Assuming that technology has advanced to allow appropriate nonlinear constitutive relationships to be developed from laboratory or field testing, two more severe problems are present when analyzing the behavior of deep foundations: (1) how were the soil properties modified by installation of the pile and (2) how will the soil properties change because of the deformations that develop during loading? With regard to the first question, the effect of pile installation on soil properties is well known. For example, the driving of a pile into sand causes loose sand to become denser with the result that a depression may be observed at the ground surface. With regard to the second question, experience shows that a gap appears in front of a laterally-loaded pile in stiff clay during cyclic loading, with severe deterioration of the resistance. While researchers have suggested methods to model the effects of pile installation and loading, none of these methods are robust enough to allow the non-expert to use them successfully.

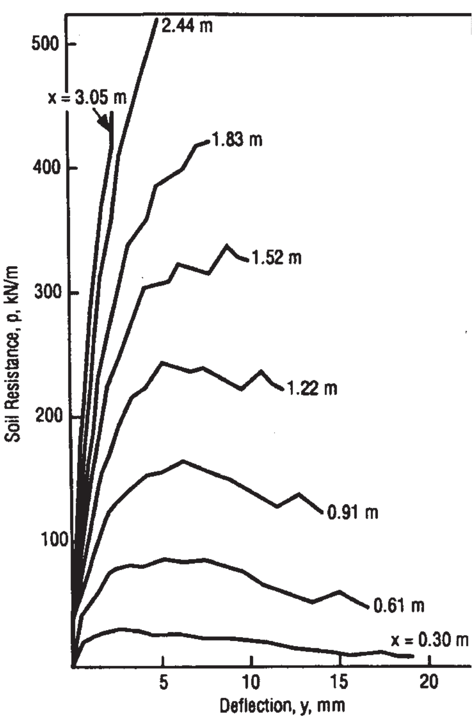


Figure 1. *p-y* curves developed from static load test of 641-mm diameter pile.

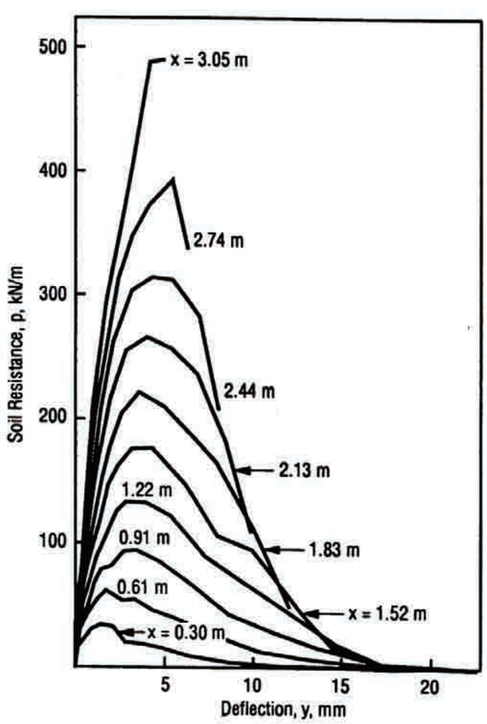


Figure 2. *p-y* curves developed from cyclic load test of 641-mm diameter pile.

See Method of Analysis, page 3

Method of Analysis

Cont. from page 2

The principal shortcomings of the FEM are that the analysis of a pile under lateral loading by FEM requires the analyst to have explicit information of stress-deformation characteristics of the soil prior to pile installation, the accounting for change of the soil properties due to pile installation and as a function of distance from the pile wall, and the effect on the soil for the type of loading, particularly if the loading reaches high levels or is repetitive. Rarely does the engineer have the knowledge, time, or budget to develop this type of information.

The conclusion can be made that FEM is a powerful method that can solve many useful problems in geotechnical engineering provided the characteristics of the soil are assumed, but general application of FEM is not now possible, especially to problems such as piles under lateral loading. The general application of FEM in deep foundations under various loadings must await the results of complicated and expensive experiments in determining the characteristics of the soil, as a function of distance from the structure, due to effects of installation and of type of loading. At present, the tools for performing the necessary experiments have not been developed.

The Method of Load-Transfer Equations

This method was first envisioned when remote-reading, electronic strain gauges became available many years ago. The gauges allowed precise measurements of the structural response of a full-sized pile under axial or lateral load. In the case of lateral loading, bending moments were measured at close intervals along the length of the pile along with measurements of pile-head deflection and rotation. Two integrations of the bending-moment curves led to deflection along the length of the pile and two differentiations led to the soil resistance. Cross plotting yielded curves, termed *p-y* curves, that reflected the response of the soil as existed around the pile. Thus, the *p-y* curves reflected the changes in soil properties: (1) that may have occurred during installation and (2) that may have occurred due to the loading of the pile. As part of the author's Ph.D. research in the 1950's, additional measurements were made of pore water pressure in the soil and were read over time to ascertain the effect of pile driving on effective stresses in the soil. Few researchers have attempted similar measurements in the five and a half decades since.

Examples of *p-y* curves developed from experimental moment curves are shown in Figures 1 and 2 for piles in over-consolidated clay with water above the ground surface. A number of facts may be gleaned from an examination of the curves. For example, the resistance of the soil due to cyclic loading, compared to resistance due to static loading, decreases markedly after deflections of 5 mm or less. As noted earlier, a gap exists in front of the pile after a small deflection, water fills the gap, and the water is ejected with a consequent erosion and loss of resistance due to repeated cycles of loading.

Correlations have been developed for *p-y* curves with properties of the particular soil into which the pile is installed, either coarse-grained or fine-grained or perhaps a rock. The derived *p-y* curves have been validated by use of soil mechanics to the extent possible. Another validation occurs when analytical results from an instrumented pile test are compared with experimental results. The method is further validated by comparing analytical results with behavior of un-instrumented piles installed in similar soil stratigraphy. Experience has shown that the method of load-transfer equations yields results that are accurate to an extent that is reasonable in geotechnical engineering.

The method of employing load-transfer equations to analyze single piles under axial or lateral loading, or pile groups under inclined and eccentric loading, is in use in engineering offices in many countries. The method is being upgraded as new information becomes available from research and feedback from thousands of practicing engineers.■

ENSOFT SHORT COURSE ON JULY 8-10, 2008

Design of Deep Foundations: Drilled Shafts and Piles Under Lateral and Axial Loading

A Seminar and Workshop Featuring Computer Programs from Ensoft, Inc.

♦ Learn how to use effective tools and proper numerical models for deep foundations ♦ Improve the efficiency of your future foundation designs ♦ Keep short course manuals and personal notes as reference for future numerical models and designs of deep foundations ♦ Use the limited 20% discount on software upgrades and new purchases for the whole office site of registered attendants to the short course ♦ Earn up to 19 PDH credits towards PE renewals for this course ♦

Single Registration *Includes refreshments and bound manuals of material on discussed topics.*	Early Rates (up to Jun 17)	Std. Rates (after Jun 17)
One-Day Session on Jul. 8	$480	$600
Two-Day Session on Jul. 9 & 10	$700	$880
All 3-Day Sessions on Jul. 8 to 10	$900	$1080

Register at: 512-244-6464 or www.ensoftinc.com

SHAFT v6.0 (New Version)

Axial Capacity of Drilled Shafts

- New soil criteria of gravelly sand and gravel based on studies by Rollins et al (2005).
- Prints a comparison of the upper-bound, lower-bound, and trend (averaged) load-vs-settlement curves together in one graph to help engineering assessment of appropriate foundation stiffness.
- Generates *t-z* curves for each soil layer and saves the data in an external text file.
- New graphical feature presenting soil profile along with predicted pile capacity as a function of depth.
- Allows users to include both side friction and tip resistance for drilled shafts in strong rock.

RECENT SOFTWARE PRODUCTS RELEASED BY ENSOFT, INC.

LPILE Plus v5.0.39 Analysis of Single Piles under Lateral Loads

PYWALL v3.0.3 Analysis of Flexible Retaining Walls

GROUP v7.0.13 Analysis of Pile Groups under Combined Loading

APILE Plus v5.0.3 Analysis of the Axial Capacity of Driven Piles

SHAFT v6.0.1 Study of Drilled Shafts under Axial Loads

UTEXAS4... Analyze of the Stability of Complex Slopes

PileGPw v2.0 Elastic Analysis for Distribution of Vertical Load and Settlement of Piles in a Group

SETOFF v3.0.1 Long-Term Consolidation (Terzaghi) of Shallow/Deep Foundations

♦ Remember to register early (by June 17) for the Summer 2008 Ensoft Short Course related to the Design of Deep Foundations and applications of Ensoft software (July 8-10 in Austin, Texas).

♦ The articles in this newsletter along with more descriptions and pictures can be found in our web site.

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