



Information gathered by the engineers of
Goble Rausche Likins and Associates, Inc. and *Pile Dynamics, Inc.*



WAVE EQUATION ANALYSIS What It Can and Cannot Do by Frank Rausche

Impact driving is a very economical method of pile installation - if it is done correctly. However, either the wrong pile driving equipment or a poor choice of pile type or pile size for the site conditions can lead to a frustrating experience at best and an impossible situation in the worst case. The contractor will spend time and money without making progress; the engineer will worry about the quality of the installed foundation and the construction manager or owner will become concerned about the project completion.

Using today's most commonly used wave equation program, GRLWEAP, and some realistic soil information, pile driving equipment can be selected that meets the demands of the project. The GRLWEAP analysis should be done early enough in the design phase such that not only the contractor's probable equipment but also pile type and pile length can be optimized for a given set of load conditions. Based on GRLWEAP results, an experienced engineer can then answer the following questions.

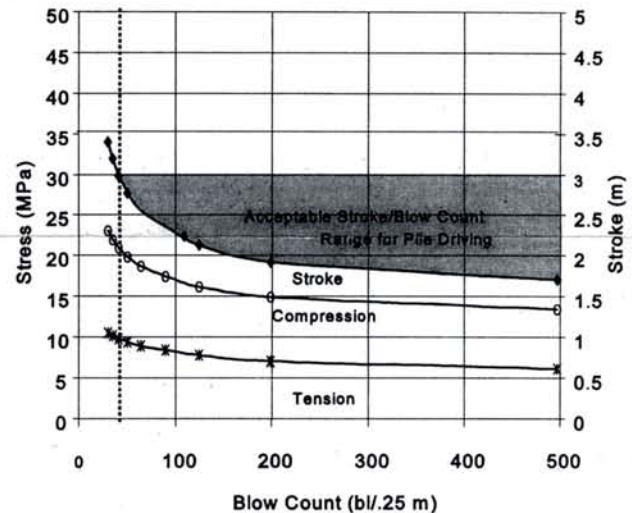
- Would a heavier pile section or a higher strength pile material allow for easier and/or safer installation?
- Will intermediate soil layer cause refusal or high stresses?
- Can the pile be driven at a reasonable blow count (e.g., below 300 b/m or 90 b/ft) to the required capacity?
- Can a follower be used without excessive loss of energy or increased pile stresses?
- What stresses will develop along the length of non-uniform piles or piles with splices or joints?
- Will it be possible to drive the pile after driving interruptions and can the pile be moved during a restrike test (set check)?

Once the engineer has found an economical pile type which can be installed with available equipment, the bid documents are prepared and a contractor is selected. The successful contractor may consider pile type and/or installation equipment that differs from the design. In that case, the contractor will repeat the GRLWEAP analysis to assure that the preferred solution is indeed feasible. In this phase the following questions may also be addressed:

- Can a cheaper, smaller or a larger faster hammer be used?
- How do diesel, hydraulic, air-steam hammers compare?
- How much cushion should be used on concrete piles?
- How much time will be required to drive the pile?

Having selected an optimal system, the contractor submits its data to the engineer who determines a driving criterion such as a minimum blow count or maximum set per blow. Where compressible soil layers overlay competent ones, a minimum pile toe depth may be specified. Other considerations include soil setup or relaxation, scour, excavation after driving, negative shaft resistance, etc. The driving criterion may be presented in the form of a graph relating blow count to hammer stroke (or energy), which the GRLWEAP calculates under the Inspector's Chart option. The example graph shows maximum stresses and acceptable stroke vs blow count, calculated for a 600 mm

INSPECTOR'S CHART for $R_u = 2000$ kN



square concrete pile that has to be driven by a diesel hammer to the required ultimate capacity of 2,000 kN. A vertical line identifies the blow count associated with maximum allowable stress, either compressive or tensile). The resulting shaded area identifies acceptable strokes for certain blow counts.

The GRLWEAP calculated driving criterion is based on a variety of assumptions. It is therefore important that its adequacy, as well as hammer performance and soil behavior, be checked in an initial pile test program using a Pile Driving Analyzer[®]. In difficult soils (e.g., relaxing), static test loading may also be needed.

The accuracy of predicted blow counts is often hampered by uncertainty about the soil resistance to pile driving and the plugging behavior of open pile profiles. Furthermore, the wave equation cannot predict:

- the pile bearing capacity at a certain depth
- the existence of obstructions
- hammer performance
- pile bending stresses or uneven contact stresses at pile bottom

GRLWEAP's user-friendly Windows based input and output features and its powerful output options make it a helpful tool even for the occasional dynamic pile analyst. However, often GRL's experienced engineers will perform an analysis for their clients on short notice.

For further information see our earlier Newsletter articles "Load Confusions", "Hydraulic Hammers and GRLWEAP", "Driving Stresses in Piles", and "What is Pile Capacity" (www.pile.com). The above described design approach is described in "Design and Construction of Driven Pile Foundations", a manual edited by GRL for the Federal Highway Administration.

NEW PUBLICATIONS AND PAPERS:

"Geotechnical Related Development and Implementation of Load and Resistance Factor Design", NCHRP Synthesis 276 (199 SYN276) is available for \$27 from: TRB Publications, P.O. Box 289, Washington, DC 20055; phone:(202) 334-3213; fax:(202)334-2519; www2.nas.edu/trbbooks/NCHRPSyn.html.

PDCA has just published "Recommended Design Specifications for Driven Bearing Piles". Copies are available for \$10 from: PDCA Code Book, P.O. Box 410260, St. Louis, MO 63141; phone: (314)275-7453; fax: (314)576-7989

"Custom Tailoring Quality Assurance for Augercast Piles" by *Frank Rausche*, *Jorge Beim* and *Michael Morgano* will be presented at the XI Panamerican Conference on Soil Mechanics and Geotechnical Engineering. See Calendar of Events.

"Automated Installation Monitoring for Augercast and Driven Piles" by *Garland Likins*, *Frank Rausche* and *Michael Morgano* will be presented at DFI's 99 Annual Members Meeting. See Calendar of Events.

"What is Foundation Failure" by *F. H. Kulhawy* and *A. Hirany*, is published in the Proceedings of the International Conference of Foundation Failures, May 1997, Singapore. This reference may be of interest to those that, like Prof. Kulhawy, felt that the issues discussed in our last newsletter article are important ones.

WWW: Dynamic Testing Web Site in Spanish and Portuguese for our Spanish and Portuguese speaking users; a good place to learn more about dynamic testing is www.pdi.com.br.

ACI IDENTIFICATION OF CUTTING EDGE TECHNOLOGY:

The PIR-A was selected by the American Concrete Institute to be presented in a special Technology Transfer Session at ACI's Fall Convention (see Calendar of Events). Technologies selected for presentation had to have "the potential for substantial beneficial impact on ... construction activities", and had to require "adoption into codes or other standards for use in concrete construction", offering "improved performance and/or lower construction costs".

COMMUNITY INVOLVEMENT:

Pile Dynamics, Inc. has joined a group of Cleveland based businesses and university leaders who are spearheading efforts to showcase the region's strengths and technological expertise in instruments and controls. The Instruments and Controls Industry Cluster has a web site, www.neoi-c.org, that was developed as part of a plan to showcase products of and to attract qualified technical talent to Northeast Ohio. Pile Dynamics is proud to be listed on the web site among many other distinguished companies.

FALL 1999 CALENDAR OF EVENTS with GRL-PDI Participation

- August 8-12:** Foz do Iguaçu, Brazil: XI Panamerican Conference on Soil Mechanics and Geotechnical Engineering. Call 55 11 31046412.
- September 30-October 1:** Seattle, WA: ASCE Continuing Education: Deep Foundations: Design, Construction and Quality Control. Call (800) 548-2723.
- October 1-2:** PDA Users Day in Gothenburg, Sweden. Call 46 31 454307.
- October 5-6:** Dynamic Pile Testing Seminar and Wave Equation Workshop in London, UK. Call 46 31 454307.
- October 13-14:** Dearborn, MI: APTLY Seminar: Pile Testing Methods II: Uses and Abuses. Call (925) 254-0460.
- October 14-16:** Dearborn, MI: DFI 99 Annual Members Meeting and Conference and Equipment Exposition: Call (734) 764-8495.
- October 29-30:** Baltimore: Dynamic Pile Testing Seminar and Wave Equation Workshop. Call (216) 831-6131.
- October 31-November 5:** Baltimore. American Concrete Institute Fall Convention Call (800) 451-1648.
- November 5-6:** San Francisco: Dynamic Pile Testing Seminar and Wave Equation Workshop. Call (216) 831-6131. Event location and final details will be mailed upon registration.
- September 11-13, 2000:** Stresswave 2000, São Paulo, Brazil.

GRL PERSONNEL NEWS:

After 15 years as staff engineer and office manager both in Colorado and Washington, Bert Miner, P.E., has decided to start his own office in Seattle. All of us at GRL and PDI will miss Bert. We wish him success in his new venture.

READERS AND CLIENTS WRITE:

Yan Goretsky, from the Technion in Israel: "More than 200 steel piles were driven and tested during restrrike (ed.) during 1998, using PDI equipment and CAPWAP program. I do appreciate very much your friendship and help." (The project Mr. Goretsky is referring to is located near Ashkelon, Israel. The piles were 48" to 72", about 100 m long.)

Theodore H. Thompson, President, Louisiana Engineering Society, complimented *Mohamad Hussein* (GRL Florida) on the seminar that he presented at the Tri-State Engineering Society Conference at Sandestin, June 20-23: "Your assistance contributed significantly to the success of our meeting, and the comments that were given by the attendees regarding your session were all very positive... We look forward to hosting a similar event next year and hope that you will consider joining us in Dallas, Texas for this event." Mohamad's presentation was entitled "Dynamic Evaluation Methods for Driven Piles and Drilled Shafts Foundations". We will feature the Tri-State Dallas event in our Calendar once information is available.

GRL

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