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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.

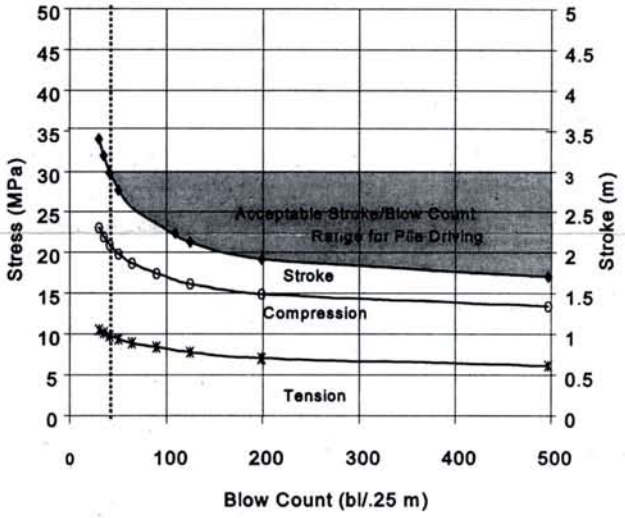
- Would a heavier pile section or a higher strength pile material allow for easier and/or safer installation?
- Will intermediate soil layer cause refusal or high stresses?
- Can the pile be driven at a reasonable blow count (*e.g.*, below 300 b/m or 90 b/ft) to the required capacity?
- Can a follower 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 Ru = 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.