GRL + PDI

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Driving Stresses in Piles

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Pile foundations must have adequate soil support **and** be structurally sound. Soil strength uncertainty causes many engineers to specify static or dynamic pile testing and relatively high safety factors. In general, the pile's structural strength is much greater than the soil strength. However, when a pile fails structurally, it is likely to have very low load capacity compared with design loads, and/or a reduced effective length, and therefore displacements under design loads are likely to be excessive, particularly under tension loads. Unfortunately, pile damage cannot always be detected by merely checking driving records. Thus, dynamic testing should be used to assess the extent and location of suspected potential damage.

Hammer impact stresses are probably the most severe conditions the pile will ever experience in its life. Therefore, driving stresses have interested engineers involved in pile driving for decades and is one of the prime reasons the wave equation analysis was developed.

Allowable stresses are determined from the static strength of the pile material. However, most experts agree that the material strength is higher under short duration loading. Furthermore, actual pile strength often exceeds the nominal material strength. Because of this extra margin of safety and because driving stresses are only temporary, experience has shown they can be allowed to be near the nominal structural material strength.

In the United States, the Federal Highway Administration recommends the allowable **axial** driving stresses given in the table below (bending stresses occurring in practice cause extreme fiber stresses to be higher).

Typical Allowable Dynamic Pile Stresses in the US

Pile Type	Compression	Tension
Prestr. Concrete-US	$0.85(f'c)-f_{pe}$	$f_{pe} + 3.0\ (f'c)^{0.5}$
Prestr. Concrete-SI	$0.85(f'c)-f_{pe}$	$f_{pe} + 0.25\ (f'c)^{0.5}$
Precast Concrete	$0.85\ (f'c)$	$0.70\ (f'y)$
Steel	$0.90\ (f'y)$	$0.90\ (f'y)$
Timber	$3\ \sigma_a$	$3\ \sigma_a$

In this table, $f'y$ is steel yield strength, $f'c$ is the 28 day strength of concrete, f_{pe} is the effective prestress and σ_a is the allowable static timber stress. The concrete tension strength limits are dimensional and are given in both USA (psi) and SI (MPa) units.

Other agencies and codes in other countries specify different limits. For readers interested in more detail, GRL will be happy to provide more information upon request.

In a **wave equation analysis, *e.g.,* GRLWEAP**, the hammer, cushions and pile are modeled and stresses are calculated at every point along the pile. If the predicted stresses are too high for the pile strength, the hammer stroke could be reduced, a smaller hammer used, the cushion made softer, the pile material strength increased, or a heavier pile section chosen. Since GRLWEAP calculates **axial** stresses, the engineer should assure that the calculated values remain below the material strength.

Did you notice this Newsletter is now called "GRL + PDI"?
We made this change because our international readers are more familiar with Pile Dynamics, Inc. than GRL.
Yet, no matter what the name,
The news is still the same.

Many engineers prescribe **dynamic measurements during driving** using a **Pile Driving Analyzer® (PDA)** to verify that driving stresses are within acceptable limits. The typical dynamic test measures the axial stresses at the sensor location (usually near the pile top). This measured axial stress is often the maximum compression stress experienced by the pile. It is logical with current practice to allow higher stresses if they are measured, rather than simply estimated from assumptions and a computer model. In fact, the Australian code, AS2159, specifically states "Where stresses are actually measured during driving, the above values (limits) may be increased by up to 10%."

The PDA also calculates the maximum tension stresses occurring anywhere below the sensors, which is important for concrete piles. The maximum compression stress at the bottom of the pile can also be estimated from wave propagation theory. Both the tension stress along the shaft and the bottom compression stress are the average axial values. Bending or local contact stresses, for example at the bottom when the pile toe encounters sloping rock, must be considered separately. The extreme fiber compression stresses for each sensor can be determined, at least in one plane. However, these extreme stresses should not be held to the same limits as established for the average axial strength.

A dynamic testing program at the beginning of production can investigate the most effective and safe method to install the piles. Axial driving stresses are then known. Adjustments can be made, if necessary, to hammer energy or cushions if stresses are excessive. If the incidence of pile damage is too high, dynamic testing can reveal the extent of the problem, and the probable cause, leading to a rational suggestion for corrective action.

Occasionally pile structural damage occurs at low driving stresses. Possible causes include poor pile quality (material, reinforcement details) or improper pile handling, non-uniformity or lack of squareness of the pile top, loose or tight helmet fit, uneven helmet surface, high local contact stresses, improper pile guiding, applying excessive bending forces, obstructions in the ground, *etc.*

Collapse of a steel pipe may be caused by too thin a section for the lateral pressures from earth pressure or from driving adjacent piles. Bottom damage may occur from obstructions or non-uniform contact with hard bearing layers such as rock. Concrete pile damage may also occur in "flexible" or "bouncy soils" causing high tension stresses.