Testing Methods of Driven Piles on INDOT Demonstration Projects

by

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INTRODUCTION:

This paper provides an overview of testing methods (WEAP, PDA, and Static Load Test) as applied to pile driving operations on INDOT demonstration projects. The implementation of these technologies within the Indiana Department of Transportation will also be reviewed.

Pile driving is a rather brutal method of foundation construction. A heavy mass hammers the pile until it is installed in the ground. When installed, the pile may be bent or straight, and it may be capable of carrying a high or low load. Since most of the pile is underground and out of sight, one is not too sure. The quality of the finished product has two aspects: The structural integrity of the pile and its ability to carry the applied load as a structural element; and the load deformation relationship between the pile and the supporting foundation soils.

INDOT BACKGROUND:

In the past, the Indiana Department of Transportation has relied entirely on the engineering news record (ENR) formula for determining pile capacities. This has sometimes resulted in excessive pile lengths and inaccurate pile capacities. In order to save money on bridge foundations, better methods of measuring pile capacities were needed.

In an effort to alleviate these problems, in April and December of 1992, the INDOT in cooperation with FHWA hosted two workshops on design and construction of driven pile foundations. These workshops were designed to address all aspects of pile foundation design and construction. The highlights of these workshops were the introduction of the wave equation analysis program (WEAP), pile driving analyzer (PDA), and the static load test.

After the completion of these workshops, the INDOT selected six demonstration projects for the implementation of these technologies. These technologies included static load test, wave equation analysis program (WEAP), and pile driving analyzer (PDA) which will be described in detail later.
Pile Driving System

The pile driving system consists of the following components:

1. Pile
2. Driving Equipment
3. Soil

Details of each of these components should be known prior to performing a dynamic analysis of the pile driving. Figure on the following page shows a layout of the pile driving system. Each of these components will be discussed below.

1. Pile

The pile information is probably the easiest to obtain since it is specified by the designer. The following pile information can be obtained from the plans, specifications, or contractor.

A. Pile Type (PPC Pile, Timber Pile, Pipe Pile, or H-Pile)
B. Pile Geometry (Specified Size, Cross-Sectional Area, and Length)
C. Specified Pile Details
D. Pile Material Properties (Concrete, Steel, or Timber)

Specific pile details refers to pile splices, PPC pile prestressing level, welded plate for load testing, followers during driving, ground elevation during driving, pile cutoffs, and plan pile tip elevation.

2. Driving Equipment

The pile driving equipment consists of the following:

A. Hammer
B. Drive Assembly:
   - Striker Plate
   - Hammer Cushion
   - Pile cap
   - Pile Cushion (concrete piles only)
C. Hammer Leads

The pile driving equipment listed is described below:

Hammer:

The pile driving hammer can be an impact or vibrating hammer. The Dynamic Analysis discussed herein shall remain limited to impact hammers.

Impact hammers operate under the principle of a heavy weight (Ram) being raised and then accelerated downward to impact the pile top. By repeating this procedure, the pile is pounded into the ground to the desired pile tip elevation.
Impact hammers can be divided into two categories according to their source of power — External Combustion and Internal Combustion.

**External Combustion Hammers** operate the ram with an outside source of power such as air, stream, hydraulic, or a cable.

**Internal Combustion Hammers** operate the ram with power produced internally within the hammer (Diesel Hammers).

These hammers can further be subdivided by the method of operating the ram — Single-Acting and Double-Acting.

**Single-Acting Hammers** operate by applying a force to the upward ram stroke and then allowing the downward stroke of the ram to fall under the force of gravity.

**Double Acting-Hammers** operate by applying a force to the ram during both the upward and downward stroke.

Single-Acting, Internal Combustion Hammers are also known as open-ended diesel hammers. Double-Acting, Internal Combustion Hammers are also known as closed-ended diesel hammers.

**Drive Assembly:**

The drive assembly consists of a striker plate, hammer cushion, pile cap, and pile cushion. The weight of the drive assembly is required when predicting hammer driving performance since its weight is part of the mass that drives the pile. Each of these components is shown on the figure and also described in detail below.

**Stroker Plate:**

The striker plate is a steel plate which is placed between the hammer and the hammer cushion. The purpose of the striker plate is to protect the hammer cushion by uniformly compressing the hammer cushion during impact.
Hammer Cushion:

The hammer cushion primarily protects the hammer. This cushion has a limited life and should be replaced when damaged. Several man-made materials with predictable properties are used as hammer cushions. The following is a list of some commonly used cushions:

<table>
<thead>
<tr>
<th>Material</th>
</tr>
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<tbody>
<tr>
<td>Micarta</td>
</tr>
<tr>
<td>Hamortex</td>
</tr>
<tr>
<td>Forbon</td>
</tr>
<tr>
<td>Nylon</td>
</tr>
<tr>
<td>Cable</td>
</tr>
<tr>
<td>Aluminum</td>
</tr>
</tbody>
</table>

Pile Cap:

The pile cap is also known as the helmet, bonnet, anvil block, or drivehead. The pile cap is a heavy and rigid steel block which is placed over the pile to prevent damage during driving. The pile cap should be sized correctly with the pile being driven. An inadequate pile cap will cause localized stresses at the pile top and may induce excessive bending stresses.

Pile Cushion:

The pile cushion is only used to protect concrete piles from damage during pile driving. Plywood and oak are the most common types of pile cushions. A thick (easy driving condition) pile cushion is usually required to protect the pile from tensile driving stresses. A thinner cushion is usually sufficient to protect the pile top from compressive failure.

Hammer Leads:

The hammer leads is a steel structure on which the pile hammer travels up and down during driving. The hammer leads are used to align the hammer and drive assembly with the pile. Several types of leads are available, depending on the relative positions of the crane and the pile. The most common types of leads are listed below.

1. Fixed Leads
2. Swinging Leads
3. Semi-Fixed Leads
4. Offshore Leads

3. Soil:

The soil can be classified as cohesive or non-cohesive soils. The soil is the source of driving resistance. This driving resistance consists of skin friction resistance and toe bearing resistance.

The total soil resistance, $R_{total}$, encountered during pile driving can be divided into a static force component and a dynamic force component.

$$R_{total} = R_{static} + R_{dynamic}$$

The static force component is dependent on the pile displacement which depends on the soil ultimate resistance and the soil quake.

The dynamic force component is the soil damping force. This force depends on the velocity of the pile.
Typical soil quake and damping parameters are listed below.

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Quake (in)</th>
<th>Damping (Sec/Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Soils</td>
<td>Skin</td>
<td>Toe</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>D/1200.05</td>
</tr>
<tr>
<td>Non-Cohesive</td>
<td>Skin</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Toe</td>
<td>0.15</td>
</tr>
<tr>
<td>Cohesive</td>
<td>Skin</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Toe</td>
<td>0.15</td>
</tr>
</tbody>
</table>

**STATIC LOAD TESTING**

Static load testing involves the application of static loads and the measurement of pile movements. The loads are usually applied in increments and the corresponding pile displacement is observed. In practice, static load testing is performed on a pile to prove that it can safely hold the design load, or to establish a design load based on ultimate pile bearing capacity.

After the test pile is installed, a waiting period is required before the pile can be tested. The waiting period is necessary to allow the soil to remold and the excess pore water pressure caused by pile driving to dissipate (set-up or relaxation).

For load application, objects of known weight, or a hydraulic jack acting against a reaction system may be used. The reaction may be accomplished by jacking against a platform loaded with dead load or a steel frame tied to reaction piles or ground anchors. If a hydraulic jack is used, the jacking system should contain a spherical head system (bearing plates) and be calibrated before each test for increasing and decreasing load. Calibrated load cells should also be included in the system.

The movement of the pile may be measured by a set of dial gages, an engineer’s level, a wire-mirror-scale system. A deformation reading accuracy of 0.01 in (per ASTM D 1143) is considered adequate.

Two types of test loading are commonly performed; the Maintained Load Method (ML) and the Constant Range of Penetration Method (CRP). INDOT selected to use the Quick ML test method because of requiring less time to perform. In this test method, the load is applied in small increments of 10% of the design load with each increment maintained for 2 1/2 minutes. Load and deflection readings are taken and the test is terminated when the total pile top movement is reached or when significant extra displacement does not result in increased loads. After the load test, the load vs. movement, load vs. time, movement vs. time, and load vs. movement are plotted to estimate the ultimate carrying capacity of test pile. The “Failure Load” is determined by Davisson’s failure criterion.
WAVE EQUATION ANALYSIS PROGRAM (WEAP)

Is a computer program that is used to simulate pile driving by creating mathematical models of the pile, driving equipment, and soil. The wave equation models the hammer, drive assembly, and pile as a series of masses and springs. The soil resistance is represented by two models - A displacement (Quake) dependent model for static resistance and a velocity (Damping) dependent model for dynamic resistance. The displacement dependent model is represented by a spring and the velocity dependent model is represented by dashpot.

An explanation of the Wave Equation Program and case studies are reported in the full paper entitled Testing Methods of Driven Piles on INDOT Demonstration Project, F. Zandi. It may be obtained by contacting Mr. Firooz Zandi, Division of Materials and Tests, 120 S. Shortridge Road, Indianapolis, IN 46219.