Identification and Application of Soil Strength Changes in Driven Pile Design and Construction

What are time effects?

By Patrick J. Harrigan, P.E.

Time effects are changes in pile capacity that occur over time. Soil setup is a time dependent increase in the static pile capacity. In clay soils, setup is attributed to increases in effective stress as large excess positive pore pressures generated during driving dissipate, as well as due to creep effects. In sands, setup is attributed primarily to aging effects and release of anchoring effects with time. Soil setup frequently occurs for piles driven in saturated clays, as well as loose to medium dense sands and fine grains as the excess pore pressures generated during driving dissipate. The magnitude of soil setup depends on soil characteristics as well as the pile material and type. Incorporation of soil setup in a driven pile design facilitates an economical foundation design. A detailed overview of soil setup can be found in Kwon et al., (2000).

Relaxation is a time dependent decrease in the static pile capacity. During pile driving, clay soils may dilate, thereby generating negative pore pressures and temporarily higher effective stresses and soil resistance. Relaxation has been observed for piles driven into dense, saturated non-cohesive soils and fine sands. Relaxation has also been observed in some weathered shales and other weak laminated rocks; unfortunately, relaxation occurs much less frequently than soil setup. An overview of relaxation can be found in Thompson and Thompson, (1999).

Methods to estimate time effects

An early method for estimating the capacity at a later time, \( T \), based on the capacity at an initial driving test was proposed by Skove and Diven (1988) and is presented below:

\[
R_t = R_i \times \frac{1}{1 + A \Delta t / \Delta t_i} \quad \text{Equation (1)}
\]

Where:
- \( R_i \) = the initial capacity at time \( t_i \)
- \( R_t \) = the capacity at time \( t_t \)
- \( A \) = factor based on soil type (suggested 0.5 for sand, 1.0 for clay 0.5 for clays)
- \( \Delta t \) = time allowed after driving where capacity is linear in log time

Skové (1988) modified the Skove and Diven expression to focus only on the change in shaft resistance as presented in Equation 2:

\[
R_t = R_i \times \frac{1}{1 + A \Delta t / \Delta t_i} \quad \text{Equation (2)}
\]

Where:
- \( R_t \) = the shaft resistance at time \( t_t \)
- \( R_i \) = the shaft resistance at reference time \( t_r \)
- \( \Delta t \) = elapsed time in days since the end of driving in days
- \( \Delta t_r \) = reference time in days (recommended to be the same as \( \Delta t \))
- \( t_r \) = driving time in days (recommended to be the same as \( \Delta t \))
Table 1. Soil setup factors after Macdonald et al. (1981)

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Range in Soil Setup Factor</th>
<th>Recommended Soil Setup Factor</th>
<th>Number of Trials and Percentage of Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>23 (96%)</td>
</tr>
<tr>
<td>Silt - Clay</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>29 (100%)</td>
</tr>
<tr>
<td>Silt</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>50 (100%)</td>
</tr>
<tr>
<td>Sand - Clay</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>12 (100%)</td>
</tr>
<tr>
<td>Sand</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>15 (100%)</td>
</tr>
<tr>
<td>Sand - gravel</td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>15 (100%)</td>
</tr>
</tbody>
</table>

* Confirmation with local experience recommended.

An example of this approach is presented in Figure 1. In the project shown, dynamic test data was acquired and analyzed using software such as the CAPWAP program. Raner et al. (2016) determined the mobilized pile capacity as well as the shaft resistance. Dynamic test data was captured at the end of initial driving as well as at 6.61, 6.64, 14.65, 14.68, and 14.81 days after the end of initial driving. During this time frame, the shaft resistance (measured by a factor of 0.7 and the total capacity measured by a factor of 0.8). This magnitude of setup was found to be economically acceptable for the project. The capaciy values of setup factors were used for preliminary estimates. However, site-specific data gathered from pile testing, dynamic measurements, or static loading tests is preferred.

Similar to the setup factor, the settlement factor is defined as the ratio of the load cell failure load divided by the capacity at the end of initial driving. Published cases of the relaxation magnitudes in various soil types are relatively limited. For piles driven over very dense soils, relaxation factors ranging from 0.6 to 0.8 have been reported. Similarly, relaxation factors of 0.7 to 0.9 have been noted for piles driven into very dense fine sands. A few published cases of relaxation factors in rock from Thompson and Thompson (2016) as well as Hankey et al. (2013) suggest relaxation factors for piles founded in some clay specimens can range from 0.5 to 0.9. Hence, it is important to check for time-dependent decrease in capacity for end bearing piles in the above noted soil and rock materials.

Quantification of time effects

There are several ways that time effects can be quantified, each with varying degrees of accuracy and cost. The charge bar is an accurate method to assess time effects is a non-stationary model of a previously driven pile. Based on the observed changes in blow count from the time of driving to the time of pile test, the change in pile capacity can be estimated using a wave equation analysis of the blow count or using a blow count versus capacity relationship. Since the energy transferred to the pile in a non-stationary model is unknown, some uncertainty exists in the assessment of the capacity change from blow count alone. This is because the blow count on the pile is caused by a change in hammer and driven system performance by a change in the dynamic soil properties and not solely from a soil strength change.

An estimate of the pile capacity change can be obtained from dynamic measurements that are acquired during the pile test. Since the energy transfer is now quantified, the change in blow count can be better assessed and the change in pile capacity more accurately quantified. The acquired dynamic measurements can also be evaluated using signal matching software to determine the mobilized capacity and the soil resistance distribution. Compared to a non-stationary model approach, this approach has significantly increased accuracy at a modest increase in cost.

Instrument of resistance tests can also be used to assess the time rate of increase by retensioning the pile at different elapsed times after the end of initial driving. The method can also be used to look at vibrations across a site or at variable pile penetration depths. Commonly, resistance tests are performed in various soil and rock materials from Hammerslag et al. (2013). are provided in Table 2.

Table 2. Typical delay time for resistance test based upon soil type

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Time Delay (t)</th>
<th>Resistance (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Sands</td>
<td>1 Day</td>
<td>70%</td>
</tr>
<tr>
<td>Silty Sands</td>
<td>2 Days</td>
<td>50%</td>
</tr>
<tr>
<td>Steady State</td>
<td>3-5 Days</td>
<td>30%</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>7-14 Days</td>
<td>10%</td>
</tr>
<tr>
<td>Shales</td>
<td>15-30 Days</td>
<td>5%</td>
</tr>
</tbody>
</table>

* Larger times may be required.

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The most definitive measure of the change in pile capacity with time can be obtained from a static loading test taken to geotechnical failure. However, this is the most expensive method and is therefore generally only performed on one or a few piles at a site.

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References


