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A difficult task for engineers and contractors is estimating the lengths of friction piles. A theoretical equation has not been developed that results in accurate pile length estimates. Empirical methods, rules of thumb and judgement based on experience are used.

This paper presents analytical guides for estimating the lengths of friction piles that the author has found useful. There is no claim of originality for these guides since they were developed from methods proposed by others which the author has found to be useful. The use of these guides requires a critical review of the results obtained to insure that they are reasonable.

Estimating length of friction piles is used primarily by foundation engineers to assure that adequate pile-friction capacity is achieved and by engineers and contractors to estimate pile contract quantities.

The guides presented herein meet both of these needs. The writer judges these guides to be applicable for driven piles up to 150 ton design load.

The basic data required to utilize these guides are boring logs containing the Standard Penetration Test (SPT) data, soil descriptions, and information on the proposed type of piling to be used such as type, design load and shape.

It is not the intent of the author to imply that these guides should replace pile load tests. Rather, they can be used as a means to estimate the length of load test piles, to supplement the load test results where soil conditions are quite variable and to provide an estimate of pile quantities prior to the making of pile load tests.

These guides are not intended to be used to evaluate potential pile settlement or pile group effects. Additional studies, which are beyond the scope of this paper, are required for such evaluations.

Boring Data

The basic data required from the borings is the SPT spoon penetration resistance and a reasonably good soil description. The use of these guides requires reasonably accurate boring data.

It is not the intent to imply that soil strength tests or special field tests will not be required. Often these guides can provide insight as to when such
It has been established that the SPT data can be approximately related to the cohesion of clay soils (Terzaghi & Peck) and to the relative density of granular soils, which can be related to the angle of sheared resistance for granular soils (Burmister). These factors provide the basis for using the boring data.

**Pile Data**

At the present time there is a wide variety of driven piling in use. Characteristics inherent to different types of piles affect their capacity and driving and must be taken into account when using these guides. The basic information required for this analysis is whether the pile is a non-displacement, straight displacement or a tapered displacement pile.

**Static Pile Capacity Method**

A number of writers, such as Moore, Chellis, Terzaghi and Peck, have developed analytical methods for determining the capacity of friction piles. Additional methods are presented in the Navy Design Manual DM-7. The basic analysis inherent to all these methods is the estimation of the pile-soil adhesion values developed over the full length of the pile. Usually some estimate of the effect of the pile point bearing is also included.

The writer's method of analysis uses the same approach. The soil friction values are determined as a function of the Standard Penetration Test values, the soil description and the type and shape of the proposed pile. A chart relating these effects was developed, based primarily upon the pile-soil adhesion values noted by Chellis and Terzaghi and Peck. This method neglects any point bearing contribution to the pile capacity since tests on instrumented piles have shown that it generally contributes 20 percent or less of the pile capacity. Fig. 1 presents estimated values of pile-soil adhesion values based upon the conditions listed above.

The use of this method of analysis is simple. After the desired pile type, working load and safety factor are determined, the incremental values of pile-soil shear are determined for the pile until a depth of pile equaling the required pile capacity is determined. A sample calculation is given in Appendix I. It should be noted that the above method of analysis requires separate evaluations of the pile capacity as a structural member, the pile group effects and pile settlement.

The writer has compared this method of analysis with the results of pile load tests where the soil conditions have been relatively uniform. The results are given in Fig. 2. The data indicates this analysis is generally conservative, probably at least partially due to omission of the bearing capacity of the pile point.

**Dynamic Pile Formula Method**

The Bureau of Reclamation has developed a method of estimating the length of friction piles based on a comparison of the SPT spoon sampler driving resistance with the driving resistance on a number of timber piles analyzed by the Engineering News formula. This approach was modified by a former associate of the writer, Guy Tabor, and is presented here.

The EN formula is known to have poor accuracy in estimating the bearing capacity of friction piles; a great number of people have recommended that...
Employing pile driving to determine pile size required capacity. Consequently, it is reasonable to use the above noted method to estimate pile lengths for projects where pile driving will be controlled by the EN formula. This method of analysis has been found to provide good estimates of friction pile lengths on projects where pile driving was controlled by the EN formula.

**Engineering News formula**

For drop hammers

\[ R = \frac{2WH}{S+1} \]

For single-acting hammers

\[ R = \frac{2WH}{S+0.1} \]

For double-acting hammers

\[ R = \frac{2E}{S+0.1} \]

where

- \( R \) is the allowable pile load in pounds
- \( W \) is the weight of striking part of hammer in pounds
- \( H \) is the effective height of fall in feet
- \( E \) is the average energy delivered by hammer per blow in ft-lbs.
- \( S \) is the average net penetration in inches per blow for the last five blows after the pile has been driven to a depth where successive blows produce approximately equal net penetration.

The approach is to relate the SPT spoon sample driving resistance to the pile design load by empirical constants that are a function of the pile type, shape and soil type. The basic formula is:

\[ P = \sum NLf \]

where

- \( P \) is the design pile load in tons
- \( N \) is the Standard Penetration Resistance in blows per foot
- \( L \) is the depth of soil represented by \( N \) in feet
- \( f \) is the empirical constant

Fig. 3 gives the values for “f” and notes the appropriate piles types and soil conditions to which they apply.

It has been found that the maximum \( N \) value that should normally be used in this equation is 50.

When SPT boring data is presented from 5 ft intervals and soil conditions are relatively uniform this equation can be readily used in a simplified form

\[ \sum N = \frac{P}{5f} \]

to calculate the expected pile length as illustrated in the example in Appendix I. Computations are for pipe piles. The same figures are applicable to uniform diameter corrugated shell. For H-piles the square size of the pile is used.

There are a number of restrictions concerning the use of this method of analysis that should be noted. (1) It should only be used for projects where a dynamic pile driving formula is to be used as the basis for driving the piling.
FIGURE 3

It has been found that in fine sand deposits the sand may develop a quick condition and lose resistance under the driving of the pile, resulting in the piles penetrating significantly deeper than the length estimated by this method of analysis. (3) If the piles are to be pre-augered then this method can be expected to significantly underestimate pile lengths. (4) The data noted for large diameter cylinder piles is tentative because it is based on very limited data. It should be used with caution.

When using this method of analysis the results should be checked against the boring logs to insure that they appear reasonable. Empirical formulas, of which this method is one, are only guides, which should be incorporated with good engineering judgment.

General Comments

It has been the author’s experience that the use of dynamic pile driving formulas for estimating the length of friction piles for some stiff clay deposits results in piles much longer than required. For these cases the piles should be driven to a specified pile tip elevation determined from a pile load test. The determination of the optimum tip elevation for the load test pile should be based on this or some other static pile capacity method.

When estimating the length of friction piles using the two guides presented above it is best to determine an expected range in pile lengths. Once the range of values has been determined a final single value can be selected by evaluating the limiting values of the range against the boring log.

REFERENCES

2. Burmeister, D. M. “Physical, Stress-Strain and Strength Responses of

APPENDIX I

ESTIMATED PILE LENGTHS - EXAMPLES

1. Static Pile Capacity Method

Design Criteria: 35T AASHO Group I Load, Safety Factor = 2, 12” pipe pile

Formula: \( L = \frac{P \times F_s}{A_c \times a \Delta L} \)

- \( P \): pile design load = 35T - 70k
- \( F_s \): Safety Factor = 2
- \( A_c \): Pipe circumference area/ft = 3.14 sq ft/ft
- \( \Delta L \): Length of pile segment
- \( a = \): Pile to soil adhesion for \( \Delta L \)

<table>
<thead>
<tr>
<th>Depth Description</th>
<th>N</th>
<th>Ftg. level</th>
<th>( \Delta L )</th>
<th>( N_a )</th>
<th>( a \times \Delta L )</th>
<th>( \Sigma a \times \Delta L )</th>
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<tbody>
<tr>
<td>Sandy Clay</td>
<td>5</td>
<td>5’-10</td>
<td>1.1-1.4</td>
<td>5.5-7.0</td>
<td>5.5-7.0</td>
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</tr>
<tr>
<td></td>
<td>10</td>
<td>7’-11</td>
<td>0.4-0.6</td>
<td>2.8-4.2</td>
<td>8.3-11.2</td>
<td></td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>8</td>
<td>8’-9</td>
<td>1.2-1.6</td>
<td>21.6-28.8</td>
<td>29.9-40.0</td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>29</td>
<td>5’-29</td>
<td>0.9-1.3</td>
<td>4.5-5.6</td>
<td>34.4-46.5 ( \xi )</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>43</td>
<td>5’-43</td>
<td>1.1-1.6</td>
<td>5.5-8.0</td>
<td>39.9-54.5 ( \xi )</td>
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</tr>
<tr>
<td>Layers Sand &amp; Clay</td>
<td>17</td>
<td>7’-12</td>
<td>0.7-0.9</td>
<td>4.9-6.3</td>
<td>44.8-60.8 ( \xi )</td>
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</tr>
</tbody>
</table>

Use \( 44' (L=39') \)
2. Dynam Formula Method

Design Criteria: 35T working load
(a) check 12" pipe pile
(b) check tapered pile

(a) use \( f=0.055 \) to 0.060, for \( \Delta L=5' \):
\[
N = 35 \times \frac{5x}{0.055} = 117 \text{ to } 127
\]
(b) use \( f=0.070 \) to 0.080, for \( \Delta L=5' \):
\[
N = 35 \times \frac{5x}{0.07} = 88 \text{ to } 100
\]

Boring Data

<table>
<thead>
<tr>
<th>Depth</th>
<th>Soil Description</th>
<th>N</th>
<th>ΣN</th>
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<td>0</td>
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<td>5</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Sandy Silt</td>
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<td>Clay</td>
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<td>30</td>
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<td>40</td>
<td>Clay</td>
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<td>57</td>
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<tr>
<td>50</td>
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<td>73</td>
</tr>
<tr>
<td>60</td>
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<tr>
<td>70</td>
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<td>15</td>
<td>145</td>
</tr>
</tbody>
</table>

Est. pile tips @ 38' to 40' Use 40' (L=35')
Est. pile tip @ 42' to 43' Use 43' (L=38')