PERFORMANCE OF BITUMINOUS COATS IN REDUCING NEGATIVE SKIN FRICTION

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Though the phenomenon of dragload is known for many decades, there is a lack of clear guidelines to evaluate the amount of dragload. The development of dragload depends on relative movement between pile and surrounding soil which is a complex phenomenon and requires a detailed numerical analysis. Bitumen layer has been used in the past with varying degree of success in reducing the dragload but the reduction appears to depend on number of parameters. No procedure is available in literature to estimate the dragload when a slip layer is applied on pile surface. This paper investigates performance of two commercially available bituminous coats to reduce the negative skin friction on pile. Direct shear test apparatus was used to model the interface friction between soil and coated pile surface. The lower half of direct shear box was replaced with either a concrete block or a mild steel block representing pile surface. Two types of bituminous coats namely Shalikote and bitumen having penetration value of 30-40 were evaluated in this study. Shearing resistance of pile material-coat-soil is found to be influenced by normal stress, coat thickness, and rate of shear. Laboratory results are compared with published field data where coated and uncoated piles have been load tested.

Introduction

The dragload is the load transferred to the pile due to negative skin friction developed on the pile shaft where surrounding soil settles more compared to the pile. Several field measurements have recorded enormous magnitude of dragload experienced by piles ranging from 300 kN (Fellenius, 1972) to as high as 7600 kN (Boozuk and Labreque, 1969). Dragload on piles can exceed the superstructure loads and may lead to structural failure of piles and/or result in excessive settlement. Dragload could have adverse effect on the economy of the project and reduction of dragload may become necessary. The pile design must ensure that the dragload is accommodated without causing any structural distress and excessive settlement of pile.

In the past, various methods have been adopted to reduce the dragload depending upon the field situation. The methods used to reduce dragload include preloading, electro-osmosis (Bjerrum et al., 1969), protection piles around pile group (Okabe, 1977), and slip layer technique using bentonite slurry or bitumen coat (Bjerrum et al., 1969). Coating the pile with bitumen is the most economical among above methods for reducing negative skin friction (Baligh et al., 1978).

The effectiveness of coating in reducing dragload depends on characteristics of the pile, the soil and the coating material itself. In case of fine grained soils, the shearing behavior of the coating depends on the average rate of settlement of soil. In case of coarse grained soils, soil particles slowly penetrate into the coat causing significant increase in the negative skin friction. Test results have shown that the negative skin friction for bitumen coated piles in coarse grained soils reaches a maximum value in less than a month and that bitumen at this stage behaves as visco-frictional material with complex properties (Baligh et al., 1978). Coating material should have low viscosity to permit the slippage of soil surrounding pile shaft and at the same time it should adhere to pile shaft during storage and pile driving. A soft and thicker coating results in lesser dragload. The cost of coated pile can be much higher than that of uncoated pile (Briaud and
Therefore the selection of type of coat and thickness is important for dragload mitigation and overall economy of the project. This laboratory investigation evaluates the performance of two types of bituminous coats in reducing the skin friction at soil-pile interface. Conventional direct shear apparatus was modified to study the soil-pile interface. Tests were carried out to study the effect of type and thickness of coat, normal stress, and rate of shear on interface friction.

Laboratory Study

Two types of coating materials were used in this study, namely; Shalikote and bitumen. Shalikote is dispersion of selected grades of bitumen in water. It is used as a protective coating over steel to prevent rusting. It has semi solid consistency. Shalikote is applied cold on a surface. It can withstand temperature variations and vibrations. The bitumen coat used in present study had a penetration value between 30 and 40 and softening point between 55°C and 60°C.

a) Interface Friction Tests with Sand

Granular soil layer, either natural or in the form of surface fill apply considerable dragload on pile due to the settlement of the clay layer below. The particle penetration of granular soil into coat during pile driving may result in scrapping off the coat and higher skin friction. Therefore it is important to study the efficiency of coating material in reducing the interface friction between pile material and granular soil.

The conventional direct shear apparatus was modified to conduct interface friction tests as shown in Fig. 1. Pile shaft was represented by a solid mild steel block or concrete block of 8.5 by 8.5 by 2.8 cm. The properties of granular soil used in study are listed in Table 1.

The granular soil used is classified as poorly graded sand (SP) and hereafter referred as sand.

Table 1. Properties of granular soil

<table>
<thead>
<tr>
<th>D_{50} (mm)</th>
<th>D_{10} (mm)</th>
<th>C_o</th>
<th>C_c</th>
<th>G_s</th>
<th>\gamma_{max} (kN/m^3)</th>
<th>\gamma_{min} (kN/m^3)</th>
</tr>
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<tbody>
<tr>
<td>0.58</td>
<td>0.28</td>
<td>2.5</td>
<td>1.18</td>
<td>2.63</td>
<td>18.2</td>
<td>15.5</td>
</tr>
</tbody>
</table>

The first set of tests was conducted to measure the peak shear stress at the interface of pile material (i.e. mild steel block and concrete block) and sand. The top half of direct shear apparatus was placed on solid mild steel block and secured in position with locking pins. Sand was placed in top half of direct shear apparatus at 70 percent relative density by pluvial deposition technique. Normal stress was then applied on the sand surface and sample was sheared. All tests were conducted at 0.25 mm/min rate of shear. The interface friction between sand and concrete block was measured using the identical procedure.

The second set of tests was conducted to study the reduction in interface friction by coating the blocks of pile material with bitumen and Shalikote. Bitumen was heated to 150°C and poured in 6 cm by 6 cm mould placed on the top of mild steel block. The coat was allowed to remain in the mould for 24 hours. After a period of 24 hours the mould was removed and the top half of direct shear apparatus was carefully placed on mild steel block without disturbing the coat.

In case of Shalikote, the semi solid coat was thoroughly mixed and applied cold at uniform thickness inside the 6 cm by 6 cm mould placed on top of mild steel block. The Shalikote took more than 24 hours to cure. The end of curing was indicated by the change in color of coat from brown to black.

Sand was then directly deposited at 70 percent relative density on top of bitumen or Shalikote coated mild steel block. Pluvial deposition technique was used to place the sand on top of coat. Manual compaction was avoided to
prevent uncontrolled penetration of sand particles into coat. The pluvial deposition technique ensured uniform coat properties before shearing. After placing sand on top of coat the desired normal stress was applied through sand on the interface. The top half of direct shear apparatus was then lifted with the help of three lifting screws so that it remains just above the top of coat as shown in Fig. 1. The soil was then sheared against the coated mild steel block at 0.25 mm/min rate of shear. All tests were conducted at an ambient temperature of 31°C. Tests on concrete blocks were conducted with procedure identical to that used for mild steel block. The reduction in interface friction was considered as a measure of effectiveness of coat.

The typical shear behavior of uncoated, shalikote coated and bitumen coated mild steel block with sand is shown in Fig. 6. Tests with Shalikote showed initial increase in interface friction followed by substantial reduction as sample was sheared. In case of bitumen, interface friction increased as sand particles penetrate into coat and then remained constant as shown in Fig. 6. Tests showed that full interface friction is mobilized at a relative movement of few millimeters. Soil undergoes large settlements compared to pile where dragload mitigation is required. In the present study shear stresses at 6 mm relative deformation are compared for evaluating the reduction in interface friction with Shalikote and bitumen.

Results of interface friction tests on Shalikote coated mild steel block are presented in Fig. 2. Results of interface friction tests on bitumen coated mild steel block are presented in Fig. 3.

Analysis of test results suggests that bitumen coat achieved maximum reduction in interface friction for all normal stresses and all thicknesses. At normal stress of 25 kPa, residual shear stresses for specimens coated with 1 mm and 1.36 mm thick Shalikote were marginally higher than those obtained for sand and uncoated mild steel block as shown in Fig. 2. This behavior may be attributed to component of adhesion of Shalikote to the mild steel block.

Specimens coated with Shalikote showed 50% and 60% reduction in shear stresses to that of uncoated specimens at normal stresses of 50 kPa and 75 kPa respectively as shown in Fig. 2. Shalikote coating showed substantial reduction in coat thickness due to shrinkage.

Initial coating thickness of 2 mm, 3 mm and 5 mm reduced to 1 mm, 1.36 mm and 2.16 mm after curing. Shrinkage of coat may pose problem of cracks when applied to surface of prototype piles in field. For Shalikote reduction in shear stress ranged from 20% to 60%.

![Fig. 2. Interface friction of Shalikote coated mild steel block.](image)

![Fig. 3. Interface friction of bitumen coated mild steel block.](image)

Bitumen coated mild steel block specimen showed 85% to 97% reduction in shear stress when compared to uncoated specimen. Shear stress decreased with increase in the coat thickness as shown in Figs. 2 and 3.

Results of interface friction tests on Shalikote coated concrete block are presented in Fig. 4. Results of interface friction tests on bitumen coated concrete block are presented in Fig. 5.
Tests on concrete blocks showed identical trends. Shalikote coated specimens showed 25% to 70% reduction in shear stresses when compared to uncoated specimens as shown in Fig. 4. Bitumen coated samples showed 85% to 97% reduction in shear stresses as shown in Fig. 5.

The available literature shows that the rate of shear has no effect on interface friction (Heerema, 1979). However these studies are limited to uncoated construction materials and soils.

Limited tests were carried out on coated mild steel block to study the effect of rate of shear on interface friction. Effect of rate of shear on interface friction for Shalikote coated mild steel block and sand is shown in Fig. 7. Tests show that interface friction is directly proportional to the rate of shear. Sand particles penetrate into coat under normal stress and shear stress which result in visco-frictional behavior of coat. Therefore interface friction developed on coated pile can be expected to vary with rate of soil settlement. The interface friction at soil-pile interface is expected to be high, immediately after placement of fill because of faster rate of settlement.
b) Interface Friction Tests with Clay

Limited number of tests were carried out to study interface friction of clayey soil with concrete block. Index properties of soil used are given in Table 2. The soil is classified as low plasticity clay (CL) and hereafter referred as clay.

Table 2. Properties of clay

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
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<tbody>
<tr>
<td>Atterberg Limits</td>
<td></td>
</tr>
<tr>
<td>Liquid Limit (%)</td>
<td>45</td>
</tr>
<tr>
<td>Plastic Limit (%)</td>
<td>19</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>26</td>
</tr>
<tr>
<td>Grain Size</td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>47</td>
</tr>
<tr>
<td>Silt Size (%)</td>
<td>27</td>
</tr>
<tr>
<td>Clay Size (%)</td>
<td>26</td>
</tr>
</tbody>
</table>

Clay with a water content of about 70% was stirred thoroughly to form slurry. The slurry was then transferred to direct shear box and was consolidated using small pressure increments to the desired test pressure. Provisions were made for top and bottom drainage. Slurry was consolidated to a pressure corresponding to that used in interface friction tests in a stepped manner. The consolidated soil sample was cut by a thin wire, trimmed and transferred on the top of concrete block. The desired normal stress was then applied and interface friction was measured. Tests were conducted at 0.125 mm/min rate of shear to ensure drained test condition. Tests were conducted for 3mm bitumen coated concrete blocks and clay to find out reduction in interface friction due to bitumen coat. Results of bitumen coated and uncoated specimens for normal stresses of 50, 75 and 100 kPa are shown in Fig. 8.

The results of interface tests on clay and concrete blocks are compared with interface friction deduced from field tests reported in literature and based on empirical procedure suggested by American Petroleum Institute (API, 2000) as shown in Fig. 15.

Analysis of Field Tests

Data available from pull out tests on instrumented piles reported by Indraratna et al. (1992) was analyzed to develop axial load transfer and relative displacement relationship often referred as t-z curve.

Fig.8. Shear behavior of coated and uncoated concrete block with clay.

Bitumen coated and uncoated cylindrical prestressed concrete piles were subjected to short term pull out tests. Pore pressures and ground movements were monitored throughout the period of investigation. Sub soil profile is shown in Fig. 9. Subsoil profile was characterized by top 4 m of weathered clay, followed by 16 m of soft marine clay and layers of medium stiff clay ranging from 6 to 8 m in thickness. The soft clay had natural water content up to 95%, a plastic limit of 25-40%, and a liquid limit of 70-100%.

Piles were driven in stages. The first two pile segments were connected on the ground to form a unit of 8 m long and driven into soil. The pile was left for 8 to 9 days before subjecting to the pull out test. When the first pullout test was completed then the next pile segment was connected and the procedure was repeated till pile was driven to a depth of 25 m.

The results of pile pull out tests on uncoated and 6 mm thick bitumen coated piles are reported in the form of pile head movement versus tension load as shown in Figs. 10 and 11 respectively.
The second field study was analyzed where an instrumented pile passing through sand, soft clay and stiff clay was subjected to compression load test (Raju and Gandhi, 1989). The subsoil profile included 5 m of sand followed by 7 m of soft marine clay and bearing layer of stiff clay as shown in Fig. 12. The soft marine clay had natural water content of 50-80%, liquid limit of 60-100% and plastic limit of 35-60%. The stiff clay layer had a natural moisture content of 30-40%, liquid limit of 60-100%, and plastic limit of 35-60%. The site was filled with a surcharge varying from 0.8 to 2 m. Precast concrete pile of 400 by 400 mm was driven and subjected to compression load up to failure. The pile was instrumented with electrical strain gauge type load cells to estimate the sharing of load by friction in various layers and end bearing.

Fig. 13 shows the load distribution curves for instrumented pile. The distribution of load obtained at various elevations of pile was reduced to skin friction developed. The relative movement required to develop the unit skin friction was deduced from load settlement curve shown in Fig. 14. The t-z curve was developed from the field data and compared to the t-z curve obtained from procedure suggested by American Petroleum Institute (2000) as shown in Fig. 15.

The interface friction developed in field and laboratory test was normalized to effective vertical stress to get the shaft friction parameter $\beta$ as defined by Burland (1973). Fig. 16 shows relation of $\beta$ with relative movement.
Fig. 13. Load distribution curves for instrumented pile (Raju and Gandhi, 1989)

Fig. 14. Load settlement curve for pile load test. (Raju and Gandhi, 1989)

Fig. 15. Comparison of mobilized friction for field and laboratory tests.

Laboratory and field data shows full development of $\beta$ at relative movement of about 5 mm. The value of $\beta$ for uncoated pile was found to be 0.13 based on load tests. The corresponding value of $\beta$ predicted by API method was 0.25. The laboratory tests on uncoated concrete block show $\beta$ of about 0.35. The $\beta$ for bitumen coated piles and bitumen coated laboratory specimens was found to be 0.05 and 0.02 respectively.
Summary

The paper presents laboratory tests to study the effect of pile material, normal stress, coat type, coat thickness and rate of shear on development of interface friction. Direct shear test apparatus was modified by replacing bottom half of apparatus with a solid block of pile material to model soil-pile interface friction. Two types of bituminous coats namely Shalikote and 30-40 grade bitumen of initial thickness of 2, 3 and 5 mm were used.

Bitumen coat achieved maximum reduction in interface friction for all normal stresses and all thicknesses. The Shalikote showed reduction in interface friction by 20% to 60% to that of uncoated specimens of mild steel block under normal stresses ranging from 25 to 75 kPa. Bitumen coated specimen of mild steel block showed 85% to 97% reduction in shear stress when compared to uncoated specimen under normal stresses of 25 to 75 kPa. The percentage reduction in interface friction is higher at higher normal stress. Shrinkage of Shalikote may pose problem of cracks when applied to surface of prototype piles.

Tests on concrete blocks showed identical trends. Shalikote coated specimens showed 25% to 70% reduction in shear stresses when compared to uncoated specimens. Bitumen coated samples showed 85% to 97% reduction in shear stresses. Shear stress decreases with increase in the coat thickness.

Tests were carried out to study the effect of rate of shear on interface friction developed on Shalikote coated mild steel surface. Tests show that as interface friction is directly proportional to the rate of shear.

Limited number of interface friction tests with normally consolidated clay and uncoated and bitumen coated concrete blocks were carried out at normal stress of 50, 75 and 100 kPa. This behavior was compared to the field data obtained from pull out and compression load tests on instrumented piles. Laboratory and field data shows that the maximum value of β is reached at a relative movement of about 5 mm. The β for uncoated pile was found to be 0.13 based on field tests. The corresponding value of β predicted by API method was 0.25. The laboratory tests on uncoated concrete blocks showed β of about 0.35.

The β for bitumen coated piles and bitumen coated laboratory specimens was found to be 0.05 and 0.02 respectively. Further study with model and prototype bitumen coated piles is needed to establish the design procedure using effective stress approach.
REFERENCES


