Behavior of piles in palm biodiesel contaminated mining sand
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ABSTRACT

This paper presents a practical procedure for preliminary assessment of axially loaded piles embedded in palm biodiesel contaminated soils. The effects of several model parameters such as palm biodiesel contaminated soil, pile length, pile cross-section geometry and pile-soil nonlinearity on the axial responses of the soil-pile system are investigated. The parametric studies show that the palm biodiesel contamination of the surrounding soils and geometric properties of the pile greatly affect the responses of the pile.

Keywords: Palm biodiesel contaminated soil, pile analysis, parametric study.

1. Introduction

Some of the major sources of surface contamination may due to the leakage of pipelines, oil wells, underground storage tanks of gas stations and stranded oil spills. But oil spills during transportation on the land or during oil drilling processes happen by accidents in most cases. Oil contamination leads to decrease in permeability and strength. It also results in an increase in soil compressibility due to decrease in soil modulus. Al-Sanad et al. (1995) found that heavy crude oil affects the strength parameters of sand more than light gas oil at all relative densities. The results of direct shear tests on sand contaminated with petroleum oil performed by Shin and Das (2001) indicate that the total stress friction angle and ultimate bearing capacity decreases with the oil content and increases in the kinematic viscosity of petroleum oil. Biodiesel is currently the most widely accepted alternative fuel for diesel engines due to its technical, environmental and strategic advantages (Benjumea et al. 2008).

The stress-displacement response of interface plays an important role on behavior of pile-soil. The stress-displacement response of interface plays an important role on behavior of pile-soil. The assessment of axial friction of piles particularly, involves the determination of the interface shearing resistance at large displacement (Bond and Jardine, 1991). An interface is generally considered to be a thin layer of soil adjacent to the construction material and the mechanical behavior of interface is affected by both surface characteristics of the construction material and the soil properties (Evgin and Fakharian, 1996). Laboratory shear tests at the interface are very useful to study the fundamental behaviour of axial friction around piles because they have well defined boundary limit conditions and only small amount of soil samples are needed to conduct interface and deformation tests (Hammoud and Boumekik, 2006).

In the past decades, research studies related to the geotechnical properties and behavior of oil and petroleum constituent-contaminated soil have been investigated (Evgin and Das 1992; Al-Sanad et al. 1995; Al-Sanad and Ismael 1997; Shin et al. 1999; Ghaly 2001; Shin and Das 2001 and Mashalah et al. 2007). Reviewed literature indicates that research on geotechnical
properties of soil contaminated with palm biodiesel is limited and also very little information is available dealing with the effect of palm biodiesel contamination of soil on pile foundation responses. Hence, the objective of the current study is to perform laboratory testing programs and theoretical investigation to determine the effects of palm biodiesel contamination of mining sand on the behavior of pile foundations. In addition, the comparison between uncontaminated and palm biodiesel contaminated mining sand are studied.

2. Soil Characteristics

The physical properties of the mining sand are given in Table 1. The particle size distribution curve of this soil is shown in Figure 1. Hence, the sand is classified as well graded soil according to the BS 5930 [British Standard BS 5930]. The mining sand used is angular and has a value of specific gravity of 2.63. The particle size distribution curve of the mining sand is shown in Figure 1. The blender of 20% pure palm oil with 80% petroleum diesel, called B20 palm biodiesel is used in the study as the contaminating material. The palm biodiesel (P.B), used was produced from palm oil through a chemical process called “Transesterification”.

Table 1: Physical properties of mining sand

<table>
<thead>
<tr>
<th>Properties</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective size, D_{50} (mm)</td>
<td>0.25</td>
</tr>
<tr>
<td>Uniformity coefficient, C_{u}</td>
<td>2.08</td>
</tr>
<tr>
<td>Coefficient of gradation, C_{z}</td>
<td>1.27</td>
</tr>
<tr>
<td>Maximum dry unit weight (g/cm^3)</td>
<td>1.565</td>
</tr>
<tr>
<td>Minimum dry unit weight (g/cm^3)</td>
<td>1.413</td>
</tr>
<tr>
<td>Specific gravity of soil solids, G_s</td>
<td>2.63</td>
</tr>
</tbody>
</table>

Figure 1: Sieve analysis for mining sand

3. Experimental results

Soil-steel direct simple shear tests were conducted on mining sand contaminated with 0%, 3%, 6% and 10% palm biodiesel (P.B) under normal stresses of 50, 100 and 200 kPa for both smooth and rough steel interfaces. Figure 2 shows the typical shear stress and vertical displacement versus shear strain relationships of soil-steel interface at different percentage of palm biodiesel contamination under normal stress of 100 kPa. The shear stress versus shear strain curves indicate a strain softening behavior, and shear strength decreases with palm
biodiesel content. The variation of vertical displacement with shear strain curves describes an initial contractive behavior however a dilative behavior is obvious as the shear strain is increased. The soil dilation increases with palm biodiesel content, and a greater dilation is observed at the rough steel interface. Increases the amount of oil contents in soil particles, the inter-particle slippage will also increase subsequently decrease the shear strength of the soil sample (Rahman et al., 2010). Similar results were also reported by Ratnaweera and Meegoda, (2006), Al-Sanad et al. (1995), Habib-ur-Rahman et al. (2007) and Kamehchiyan et al. (2007). Hu and Pu (2004) indicated that interface shear strength and soil dilatancy increase with increases of interface roughness.

![Shear Stress vs. Shear Strain](image1)
![Vertical Displacement vs. Shear Strain](image2)

(a) Smooth Steel Interface  
(b) Rough Steel Interface

**Figure 2:** Typical curves of shear stress and vertical displacement versus shear strain

### 4. Theoretical analysis

It is of interest to investigate the difference in response for piles embedded layered mining sands contaminated with different palm biodiesel contents. The experimental results obtained from the palm biodiesel contaminated mining sand and steel interfaces tests (Sim and Lee 2012) were employed to derive the required soil parameters for the theoretical studies of pile foundations using the boundary element method as listed in Table 2. This method can be particularly useful for identifying the patterns of deformations and load distributions in the pile foundations at all loading stages. The nonlinear boundary-element analysis was carried out using the commercial program REPUTE (Geocentrix Ltd, 2002). In all cases, soil Poisson’s ratio, \(v_s\), and \(R_f\) are assumed to equal to 0.5 and 0.9, respectively.
Behavior of piles in palm biodiesel contaminated mining sand

Table 2: Soil parameters used in theoretical analysis

<table>
<thead>
<tr>
<th>Palm Biodiesel content (%)</th>
<th>Friction Angle, $\phi$ (°)</th>
<th>$K_s$</th>
<th>Pile Diameter, $d$ (m)</th>
<th>L/d</th>
<th>Pile Modulus, $E_p$ (GPa)</th>
<th>Soil Young’s Modulus, $E_s$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>35</td>
<td>0.43</td>
<td>0.3, 0.5, 1.0</td>
<td>30, 60 or 100</td>
<td>5, 25, 40</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>0.50</td>
<td>0.3, 0.5, 1.0</td>
<td>30, 60 or 100</td>
<td>5, 25, 40</td>
<td>30</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>0.58</td>
<td>0.3, 0.5, 1.0</td>
<td>30, 60 or 100</td>
<td>5, 25, 40</td>
<td>20</td>
</tr>
</tbody>
</table>

4.1 Homogeneous Mining Sand Contaminated with Palm Biodiesel

Figure 3 shows load-displacement curves for a pile 30m long (L) and 0.5m (d) in diameter embedded in homogeneous mining sand contaminated with 0%, 10% and 15% palm biodiesel contents. The analysis predicted the pile capacity decreases with increasing palm biodiesel content. The distribution of the load in the pile is shown in Figure 4 for mining sand contaminated with various palm biodiesel contents. Load transfer along the pile decreases as the palm biodiesel contamination increases.

![Figure 3: Load-displacement curves for homogeneous soils ($E_p$=25 GPa, L=30m and L/d=60)](image)

![Figure 4: Load distribution along pile in homogeneous soils ($E_p$=25 GPa, L=30m and L/d=60)](image)

4.2 Three-layered palm biodiesel contaminated mining sands

Figure 5 shows a hypothetical pile embedded in three different layered mining sands (Case I, II and III). In each case, the soil profile consists of three layers of mining sands, each with contamination equivalent to different palm biodiesel content.
Figure 5: Hypothetical pile in layered mining sands contaminated with different palm biodiesel contents

Figure 6 shows that the axial pile stiffness affects its load-displacement curves behavior and its peak load in mining sand contaminated with different palm biodiesel content. The initial pile-soil stiffness response increases with increasing pile stiffness. It appears that case I exhibits the highest pile capacity while case II indicates the lowest pile capacity. It is interesting to note that the pile seems to have similar peak loads in case III independent of the pile stiffness. Figure 7 shows that the pile-stiffness has little effect on the load distribution along the pile in all the three cases of layered soil contaminated with palm biodiesel.

Figure 6: Effect of pile slenderness on load-displacement curves in layered soils (L=30 m and d=0.5m)
Figure 7: Effect of pile slenderness on load distribution in layered soils (L=30 m and d=0.5 m)

Figure 8 shows the relationship between load-displacement curves and pile slenderness ratio (L/d). The pile capacity decreases with increasing pile slenderness ratio in all the three cases. Figure 9 indicates that the decrease in load transfer of a pile of constant length as the pile diameter decreases. The presence of palm biodiesel contamination in the mining sand also affects the load transfer distribution along the pile.
Figure 8: Effect of pile slenderness on load-displacement curves in layered soils (L=30 m and $E_p=25$ GPa)

Figure 9: Effect of pile slenderness on load distribution in layered soils (L=30 m and $E_p=25$ GPa)

Figure 10 shows the decrease in settlement of a pile of constant length as the pile diameter decreases. The analysis suggests that very slender piles ($L/d=100$) seem to exhibit larger settlement in case I than in cases II and III. It is noted that all three cases of layered soils tend to have similar settlement response as the pile slenderness decreases.
Figure 10: Normalized pile settlement versus pile slenderness ratio in layered soils (E_p=25 GPa)

5. Conclusions

A nonlinear boundary element analysis with soil parameters derived from experimental results obtained from the palm biodiesel contaminated mining sand and steel interfaces tests has been employed to obtain theoretical response of a hypothetical pile embedded in mining sands contaminated with different palm biodiesel contents. Based on the theoretical results, the following conclusions can be drawn:

1. The pile load capacity decreases with increasing palm biodiesel content in homogeneous soil. Load transfer along the pile decreases as the palm biodiesel contamination increases.
2. The initial pile-soil stiffness response increases with increasing pile stiffness. It appears that the pile-stiffness has little effect on the load distribution along the pile in layered soil contaminated with palm biodiesel.
3. The pile capacity decreases with increasing pile slenderness ratio in layered soil contaminated with different palm biodiesel contents. Decrease in load transfer of a pile of constant length as the pile diameter decreases.
4. Long very slender piles seem to exhibit larger settlements in layered soil contaminated with palm biodiesel.

Nevertheless, the theoretical solutions should be investigated further and also verified by actual measurements from both model and field pile tests in soil contaminated with palm biodiesel.

6. References


