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Effect of Bentonite and Polymer Drilling Fluids on Skin Friction of Bored Piles

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Abstract: Skin friction is a major component in calculating the bearing capacity in any type of pile foundation. In terms of a floating pile, almost entire bearing capacity depends on the skin friction. Most of the high-rise structures in Sri Lanka stand on bored pile foundations. Construction of bored piles widely involves usage of Bentonite as a drilling liquid and as a borehole soil stabilizer which may result in retention of a considerable amount of Bentonite and soil mix between the pile and the surrounding soil. Hence it is arguable that the used Bentonite slurry has an effect on the skin friction of the pile. Polymer liquid is not a commonly used drilling liquid in Sri Lanka but still it has been used in the current study. Main objective of this research is to investigate the effect of using Bentonite and Polymer liquids on the skin friction of pile foundations in Sri Lankan soils. From the results obtained from the direct shear tests conducted in the laboratory, it was evident that polymer liquid had no significant effect on soil strength parameters but with time, due to the filter cake formation, bentonite will cause a significant change in soil strength parameters.

Keywords: Skin friction, Pile foundation, Bentonite, Polymer

1. Introduction

The pile foundation system is one of the most popular and widely used foundation systems in the world. Piles have provided a solid foundation to various structures in Sri Lanka hence, the importance of a pile foundation can never be ignored. There are two main types of pile foundations, end bearing piles and friction piles. End bearing piles are socketed into the bed rock with the pile toe resting on the bed rock. Friction piles entirely depend on the skin frictional resistance between the pile and the soil or rock.

2. Literature

2.1 Bentonite and Polymer

Fundamental property of bentonite is its expansiveness and swelling due to water absorption. Bentonite is found in three main types, namely, Calcium bentonite (Calcium Montmorillonite), Sodium bentonite (Sodium Montmorillonite) and Sodium activated Montmorillonite. Sodium bentonite has high swelling, high liquid limit and high thermal durability qualities. Bentonite has a variable particle size, ranging within a mean particle size of 2.5 to 4.0 microns [1]. Sodium bentonite (Na^+) has a higher water absorption ability and comparaively Calcium bentonite (Ca^{2+}) has a lower absorption ability due to its strong positive charge [2].

A polymer can be defined as an organic chemical with molecular weight over 200 and over eight repeating units [3]. Polymer liquids provide better shear thinning and better hole cleaning properties which are adjustable to drilling requirements. Most polymers have temperature limits below 150 degrees Celsius but under certain circumstances they are used at higher bore hole temperatures as well [4].

2.2 Skin Friction

According to the modified direct shear tests conducted for saturated silty sand by Gaurina-Medimurec [5], addition of bentonite slurry in between concrete and soil interface has resulted in reduced skin friction. According to a maintained load and constant rate of penetration test conducted by Gravador [6], Bentonite has not shown an adverse effect on skin friction of piles for London clay. A field trial, conducted in East London by Chen & Patel [7], which consisted of two test piles which used polymer fluids, has shown much

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stiffer load-settlement response compared to the test pile with bentonite drilling liquid.

Polymer fluids used for pile construction had little effect on surface shear strength in sands compared to use of water. When bentonite drilling liquid was used in sand, it was found that the concrete sand interface shear strength decreased more or less linearly with the square root of the filtration time [8].

Many designers neglect the point resistance of a pile in clay because as much as 85% of the pile load will be taken up by the skin friction and, by observations obtained on instrumented pile test data where distribution of skin friction along the depth of the pile was analysed, skin friction in clay soils appeared to increase with depth [9].

2.3 Problem Statement

Combination of Sri Lankan soils and bentonite/ polymer drilling liquid is yet to be analysed and studied in terms of skin frictional resistance of pile foundations. No proper investigation had been carried out in terms of the skin frictional effect of drilling liquids such as bentonite and polymer liquid in locally available soils.

3. Methodology

3.1 Soil Samples

Laterite soil used for the experiment (Figure 1) was extracted from the samples collected from Padukka, Western Province, Sri Lanka.

Figure 1- Laterite Soil used for the Experiment

After extracting the laterite soil samples, modified Proctor compaction tests were carried out to obtain maximum dry density and optimum moisture content (Figure 2) for laterite soil. Modified Proctor compaction tests were carried out in the Department of Civil Engineering, University of Moratuwa.

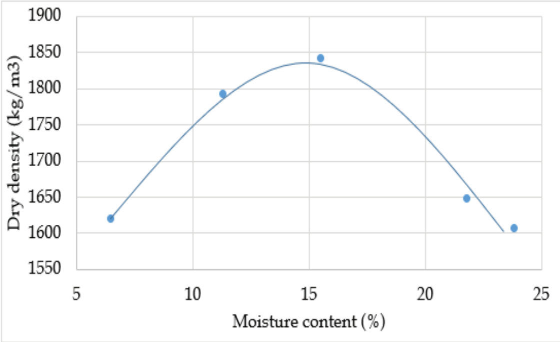


Figure 2 - Modified Proctor Compaction Test Results

Maximum dry density = 1830 kg/m^3
Optimum moisture content = 15%

Soil (laterite) was compacted to maximum dry density and samples were extracted using the sample cutter. Soil samples (laterite) were kept completely submerged in water (Figure 3) and they were given ample time for saturation.

Figure 3 - Soil Samples kept Submerged in Water

Sand used for the experiment was commercially available river sand (Figure 4). Sand samples were kept completely submerged in water and they were given ample time for saturation.

Figure 4 - Commercially Available River Sand

Direct shear tests were conducted to obtain shear strength parameters of the required soil-concrete-drilling liquid interfaces. Hence the compacted soil samples were extracted to the shear box size of 6 cm x 6 cm.

3.2 Drilling Liquids

Dry bentonite and polymer samples were collected from a well reputed piling contractor in Sri Lanka. They were the exact material which were used in industrial piling purposes. Drilling liquids were prepared in the laboratory using a mechanical mixer according to the industrial specified specific gravity parameters. Specific gravity values of the prepared drilling liquids are as follows.

Bentonite drilling liquid = 1.05
Polymer drilling liquid = 1.01

3.3 Direct Shear Tests

Direct shear tests were conducted in the Department of Civil Engineering, University of Moratuwa. Initially direct shear testes were carried out for laterite soil and sand in order to obtain shear strength parameters, cohesion and friction angle.

Second round of direct shear tests were conducted in order to obtain shear strength parameters of laterite soil-concrete and sand-concrete interfaces Afterwards, direct shear tests were carried out in the laboratory to obtain shear strength parameters for soil - drilling liquid - concrete interfaces as follows.

1. Soil- freshly prepared bentonite-concrete interface
2. Soil-bentonite-concrete interface after 7 days
3. Soil-freshly prepared polymer-concrete interface
4. Soil-Polymer-Concrete Interface after 7 days

In the shear box, concrete sample (6 cm x 6 cm) was placed at the bottom (Figure 5) and the soil sample was placed at the top.

Figure 5 - Concrete Sample was Placed at the Bottom of the Shear Box

Bentonite and polymer drilling liquid was applied (approximately 2 mm thick) on soil surface before placing them in the shear box for fresh state testing. For direct shear tests, done after 7 days for soil-drilling liquid-concrete interfaces, drilling liquids were applied on the soil samples (approximately 2 mm thick) and kept undisturbed in saturated state for 7 days (Figure 6) and taken for the direct shear tests. All the direct shear tests were conducted under fully saturated condition.

Figure 6 - Soil Samples with Drilling Liquid kept for Saturation

For each sample, shearing was conducted under 3 different normal loads, 50 kPa, 100 kPa and 150 kPa. Shear strength and shear displacement readings were taken at regular intervals until the failure of the sample/ interface. Shearing rate/speed of direct shear apparatus was set to 0.01 mm/sec.

4. Results and Discussion

4.1 Direct Shear Test Results for Laterite Soil-Drilling Liquid-Concrete Interface

Results obtained from direct shear tests for laterite soil are given in Table 1.

Table 1 - Direct Shear Results Obtained for Laterite Soil

	Cohesion (kPa)	Friction angle (Degrees)
Laterite soil only	23	26
Soil and concrete interface	6	19
Soil, fresh bentonite and concrete interface	6.5	19.5
Soil, 7 days old bentonite and concrete interface	11	11
Soil, fresh polymer and concrete interface	3	20
Soil, 7 days old polymer and concrete interface	6	19

Initial cohesion and friction angle values for the soil concrete interface were 6 kPa and 19 degrees, respectively. No significant change was shown in cohesion and friction angle values when fresh bentonite was involved in the soil concrete interface. But, after 7 days, cohesion value for soil, bentonite and concrete interface has increased significantly to 11 kPa and friction angle has decreased to 11 degrees. Fresh bentonite will not form a filter cake with soil instantly, hence the soil parameters will not be affected much. But, with time, bentonite will form a filter cake layer with soil which will appear as a clay layer when observed carefully. Due to this filter cake forming process, cohesion of the soil surface has increased, and the friction angle has decreased with time.

But for polymer, there was no visible filter cake formation on soil surface, hence interface shear strength parameters will remain unaffected after 7 days. At fresh state, polymer liquid will behave as a lubricating agent in between the soil and concrete surfaces. This has resulted in decreased cohesion for the soil-concrete interface.

4.2 Direct Shear Test Results for Sand-Drilling Liquid-Concrete Interface

Results obtained from direct shear tests for sand are given in Table 2.

Table 2 - Direct Shear Results Obtained for Sandy Soil

	Cohesion (kPa)	Friction angle (Degrees)
Sand only	0	27
Sand and concrete interface	0	19
Sand, freshly prepared bentonite and concrete interface	1.5	19
Sand, 7 days old bentonite and concrete interface	2	18.5
Sand, freshly prepared polymer and concrete interface	0	16.5
Sand, 7days old polymer and concrete interface	0	20

Initial cohesion and friction angle values for the soil-concrete interface were 0 kPa and 19 degrees respectively. With the addition of bentonite, cohesion has been increased for sand-concrete interface. After 7 days, further increase in cohesion has been observed. Bentonite filter cake layer formation can be the most probable reason for this variation. Variation of shear strength parameters for sand-polymer-concrete interface is marginal. Significant changes have not been observed in fresh state and after 7 days.

4.3 Effect of Bentonite on Cohesion of Soils

When it comes to bentonite drilling liquid, main consideration was the filter cake formation of the soil surface. Table 3 gives the values of cohesion for two soils.

Table 3 - Cohesion Values in kPa for Sand and Laterite Soil with Bentonite Drilling Liquid

	Soil-concrete interface	Fresh drilling liquid	Interface after 7 days
Laterite soil	6	6.5	11
Sand	0	1.5	2

Laterite soil has formed a filter cake layer on the soil surface after 7 days and this has led to a higher cohesion between soil-concrete interface. Laterite soil has less permeability and hence it has taken time for bentonite drilling liquid to penetrate into soil and form a filter cake layer on the soil surface.

Sand is a considerably permeable soil type. Hence bentonite has penetrated into sand in a little time period and has formed a bentonite filter cake layer on the surface. Due to this reason, cohesion for sand-concrete interface has increased even in the fresh state of bentonite drilling liquid, and after 7 days the cohesion value has increased slightly.

4.4 Effect of Bentonite on Friction Angle of Soils

Friction angle values of soil – concrete interface with bentonite are given below in Table 4.

Table 4 - Friction Angle Values in Degrees for Sand and Laterite Soil with Bentonite Drilling Liquid

	Soil-concrete interface	Fresh drilling liquid	Interface after 7 days
Laterite soil	19	19.5	11
Sand	19	19	18.5

With bentonite drilling liquid, variation of the friction angle is insignificant for sandy soil. Even after 7 days, values have remained almost the same. For laterite soil, there is no significant variation in friction angle at the point of immediate fresh mix with bentonite but the value has dropped by almost 40% after 7 days. Probable reason for this scenario would be the filter cake formation of the laterite soil with bentonite after 7 days.

4.5 Effect of Polymer on Cohesion of Soils

As a drilling liquid, polymer has somewhat similar effect on laterite soil and sand when it comes to cohesion. Cohesion values are given in Table 5.

Table 5 - Cohesion Values in kPa for Sand and Laterite Soil with Polymer Drilling Liquid

	Soil-concrete interface	Fresh polymer	Interface after 7 days
Laterite soil	6	3	6
Sand	0	0	0

Considerable amount of polymer liquid has retained in the less permeable laterite soil surface in freshly applied state, and it has behaved as a lubricating agent between soil surface and concrete surface. Hence, after immediate testing, a slight drop in cohesion was observed for laterite soil-concrete interface. After 7 days, cohesion has been restored to the initial values for laterite soil, polymer-concrete surface.

Retention of polymer liquid would be much lesser in permeable sandy soil surface due to the infiltration of drilling liquid into sand. Hence the lubricating effect between sand and soil surfaces were insignificant. Due to this reason no variation in cohesion was observed in sand, polymer-concrete interface.

4.6 Effect of Polymer on Friction Angle of Soils

Friction angle values for surfaces with polymer drilling liquid are given in Table 6.

Table 6 - Friction Angle Values in Degrees for Sand and Laterite Soil with Polymer Drilling Liquid

	Soil-concrete interface	Fresh drilling liquid	Interface after 7 days
Laterite soil	19	20	19
Sand	19	16.5	20

Variation of the friction angle with polymer drilling liquid is marginal for both laterite and sandy soils. Since there was no filter cake formation with polymer liquid, no changes were observed in the soil surfaces. Even after 7 days, friction angle values remain constant without a significant change in both laterite soil and sand.

4.7 Discussion of Direct Shear Test Results

In the long run, bentonite forms a filter cake layer on both soil surfaces. In sandy soil, rapid bentonite filter cake formation can be expected. Main reason behind this incident would be the higher permeability of sandy soil.

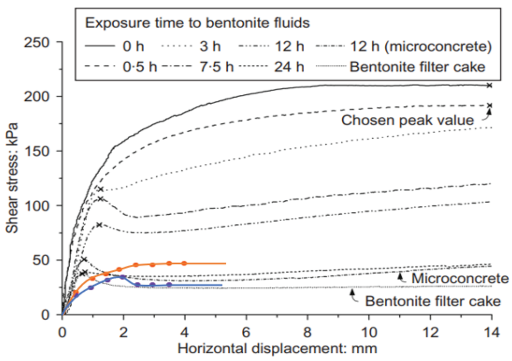
However due to the formation of the filter cake layer in both soil types, friction angle of the soil-concrete interfaces has reduced. This can have an adverse impact on the skin friction of pile shafts.

Polymer liquid and soil have not indicated any formation of a filter cake layer. At the immediate mix state, polymer tends to behave as a lubricating agent between the soil and concrete, which might lead to a loss in friction. It can adversely affect skin friction of pile shafts.

There can be practical difficulties when using polymer drilling liquid in sandy soils. Due to reduced cohesion, it can be difficult to retain sand around the borehole without a casing. This may not be the case when it comes to drilling in sandy soil using bentonite drilling liquid.

Due to thixotropic properties, viscosity of bentonite filter cake layer may increase with time which might be favourable for skin friction of piles.

A comparison of results has been carried out with a similar study done by Lam et al. [3] for sand-concrete interface with bentonite drilling liquid. From the results obtained from the past study, relevant shear stress vs horizontal displacement curves for a normal stress of 360 kPa for various exposure times to bentonite fluids have been potted in the graph (Figure 7).
Shear stress vs horizontal displacement variation for a normal stress of 100 kPa obtained for local sandy soil-bentonite-concrete interface from direct shear testing in the current study had been plotted in the same graph for a comparison.



Sand-7 days old bentonite-concrete interface

Sand-fresh bentonite-concrete interface

Figure 7 - Comparison of Obtained Results vs Past Studies [3]

Curve in blue colour has been plotted for sand-7 days old bentonite-concrete interface and curve in orange colour has been plotted for sand-fresh bentonite-concrete interface (Figure 7).

Due to the differences in the applied normal stresses, obtained peak values of shear stresses are different.

Plotted shear stress variation with horizontal displacement for sand-fresh bentonite-concrete interface is similar to 0 hour and 0.5-hour bentonite exposure curves given in the above graph.

Also, for sand-7 days old bentonite-concrete interface, plotted shear stress variation with horizontal displacement is similar to the curve 'bentonite filter cake.'

5. Conclusion

Based on the results, it can be concluded that in the long run, bentonite increases the cohesion of both sand and laterite soil-concrete interfaces while reducing the friction angle. However, with polymer, in the long run, strength parameters have re-settled to the original soil-concrete interface values hence there will be no significant difference in skin friction.

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