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Effect of Bentonite Support Fluid on Pile Capacity

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Abstract. Bore hole stability is a major problem to be resolved in all the piling sites. Support fluids play a major role in stabilizing the pile bore holes. Among the various support fluids commercially available for stabilizing bore holes, bentonite support fluid is commonly used in almost all piling sites. A study on the effect of these bentonite fluids at pile – soil interface will be highly beneficial for engineers. In this paper, an attempt is made to study the effect of bentonite layer on frictional resistance at pile - soil interface and how it affects the estimation of pile capacity. The behavior of bentonite fluid in various types of soils was also studied.

Keywords: Pile Capacity, Frictional Resistance, Bentonite Fluid, Direct Shear Test

1 Introduction

Stabilization of soil in pile borehole is of prime importance for installation of cast-in-situ concrete piles. Various support fluids like bentonite (Calcium or Sodium based),polymer etc are commercially available for stabilising bore holes. Among these, bentonite support fluid is most commonly used in almost all piling sites due to its ease in availability, ease in handling and economy. So a study on the effect of these bentonite support fluids at pile-soil interface will be highly beneficial for engineers. Effect of bentonite layer on frictional resistance at pile surface is to be studied and results could possibly affect the pile capacity calculations recommended by Indian Standards. Behaviour of bentonite fluid in various types of soil is also important.

The history and formulation of excavation fluids and their uses for the construction process were studied by Jefferis et al. [4]. The effect of water content, normal stress and rough surface on the relationship between shear stress and shear displacement of clay-concrete interface were analysed by Shakir and Zhu[8]. An interface simple shear apparatus was used for their studies. They have compared the results obtained from the simple shear tests and that obtained from the direct shear tests. It also involved using bentonite and polymer slurries as an interface layer between soil and concrete [9].

Lam et al. [5] presented a field trial in which the construction and testing of three piles were carried out at Stratford in east London. Maintained load tests done on the three test piles showed that the polymer fluids had better load-settlement behaviour and longer excavation open time without compromising the performance of the foundation. Lam et al. [6] conducted shear tests on concrete–sand interface using both polymer and bentonite support fluids and has compared their performance. From their findings, it was found that polymer support fluids do not form filter cake layer at the interface and hence provide an agreeable alternative to the bentonite slurry, which is commonly used in piling.

Rugang et al. [7] have presented the effect of water-based drilling fluid components on filter cake structure. Physical modelling of pile was done by Shrivastava et al. [10] to find out the uplift capacity of bored pile. Firstly, a modelled pile was bored without use of drilling fluid and by using different percentage of bentonite and also using different percentage of polymer. The pull out test was then performed on the fabricated test set up. The test results were compared with the theoretical uplift capacity suggested by IS 2911 (Part 1/sec2) [2]. Yoo and Han [11] has conducted shear tests to examine the performance of drilling fluids at concrete- soil and concrete -rock interface, particularly in the presence of seawater. From the results it was found that polymer drilling fluid outperformed bentonite.

1.1 Need for the study

For the excavation to remain stable, formation of a layer of filter cake with bentonite slurry is essential. But in the case of friction piles, the presence of filter cake adversely affects the load carrying capacity of piles as it can reduce the interfacial resistance. Many investigations have been carried out to study the effect of bentonite filter cake on interface resistance, but no studies came out with clear conclusions that can be practically applied in the field.

Bentonite reduces the side resistance even with thin mud layer produced by exposing the hole for slurry for short time. Studies to examine the effect of thin layer slurries between soil and concrete are limited and need more investigation. Direct shear and simple shear tests are more practical than large-scale tests and most favorable for detailed studies. Studies on concrete-soil interface resistance will be beneficial for estimating quantitatively, the effect of presence of bentonite filter cake on the actual load carrying capacity of pile foundations.

2 Materials and Methods

Bentonite was the main material used for the study. For representing the pile surface, cement mortar blocks were precast, for which Ordinary Portland Cement was used. For studying the effect of bentonite on frictional resistance at pile-soil interface, different soil types were used for conducting direct shear tests. Sand (fine, medium, coarse), clay and red earth were used to represent soil surrounding the pile.

Sand used for the study was river sand, procured from Kalady, which is a branch of the Periyar river – was dried and sieved into different fractions. River sand of three grades - fine(75µm - 425 µm), medium(425 µm – 2 mm) and coarse(2mm – 4.75mm) as per BIS 1498 classifications were used in the present study[1]. The grain size distribution curves of different fractions of sand are shown in figure 1.

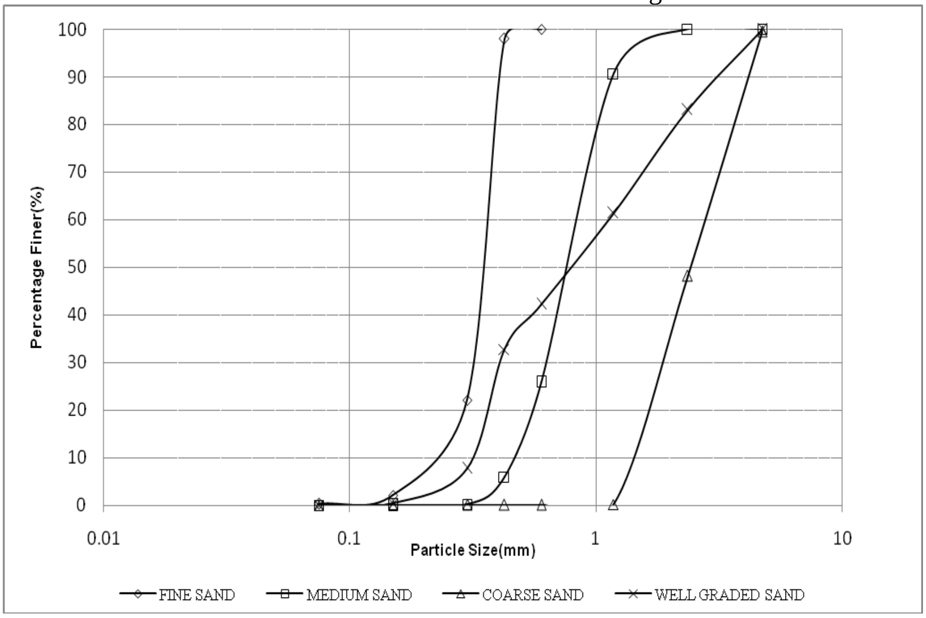

Fig.1. Grain size distribution curves of different fractions of sand

43 grade Ordinary Portland cement confirming to IS 8112 was used for making cement mortar blocks of size 60 x 60 x 12.5 mm [3]. The cement was kept in air tight container to avoid any change in properties with the time of storage. The physical properties of cement are presented in table 1.

Table 1. Properties of the cement used.

Sl. No.	Property	Characteristic value
1	Standard Consistency	37 %
2	Initial setting time	118 minutes
3	Final setting time	216minutes
4	Blaine's Specific Surface	298524mm^2/g
5	Specific Gravity	3.14

The bentonite used in this study is a commercially available, highly expansive sodium bentonite. Bentonite shows a great affinity towards moisture. The percentage of water present in the sample of bentonite varies depending on the climatic conditions. So bentonite was preserved in highly airtight polythene bags. Marine clay was collected from a site at Cheranalloor, Ernakulam, Kerala. Samples were collected from bore holes advanced by auger method. Proper attention was given while collecting clay samples, as it should not get mixed up with bentonite and was properly collected in polythene bags, so that its natural moisture content is preserved while conducting the laboratory tests. Red earth used for the study was obtained from a site at Ernakulam, Kerala. It was collected in polythene bags so that its properties will not change at the time of laboratory tests. Properties of bentonite, marine clay and red earth used for the study and its grain size distribution are shown in figure 2 and table 2 respectively.

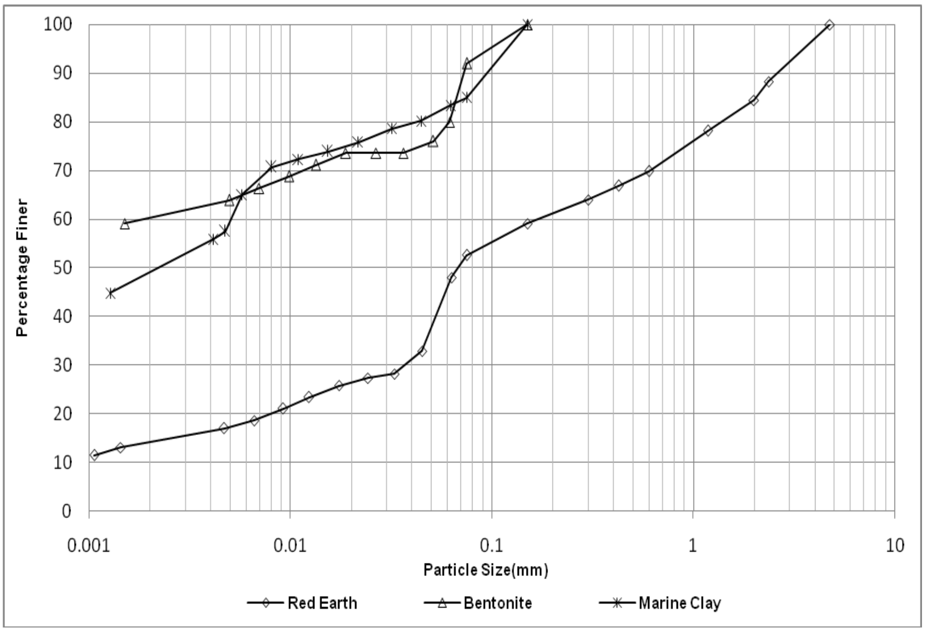

Fig.2. Grain Size distribution curves of Red Earth, Bentonite and Marine Clay

Table 2. Properties of Bentonite, Marine clay and Red earth used for study

Sl. No.	Property	Bentonite	Marine Clay	Red Earth
1	Natural moisture content (%)	-	76	27
2	Liquid Limit(%)	386	115	65
3	Plastic Limit(%)	56	46	41
4	Plasticity Index(%)	330	59	24
5	Shrinkage Limit (%)	7	23	36
6	Free Swell Index	1300%	3.6cc/g	-
7	Clay (%)	61	48	16
8	Silt (%)	31	37	37
9	Sand (%)	8	15	47

The cement mortar block was precast using a mild steel mould (60x60x25 mm) and plate (60x60x12.5 mm) assembly. Concrete mix was prepared by standard procedure which was followed in casting mortar cubes for compressive strength test. Immediately after mixing, the mortar was filled into the mild steel mould and plate assembly. Filling was done by giving compaction manually. After 24 hours, cement mortar blocks were removed from the mould and kept for 28 days of curing as shown in figure 3.

(a) (b)

Fig.3. Cement mortar blocks (a) cast in moulds (b) kept for curing

3 Methodology

For finding the interface frictional resistance, several laboratory tests like model pile tested in a triaxial cell, direct shear tests (concrete on sand or sand on concrete),model pile in centrifuge etc can be adopted [8,9]. But direct shear and simple shear tests are more practical than large-scale tests and considered optimal for detailed studies.

Among these tests, direct shear test using a direct shear apparatus with shear box size 60mm x 60 mm x 50 mm was selected for the study. A cement mortar block of 60mm x 60 mm x 12.5 mm was placed in the lower half of shear box and a layer of bentonite was spread over this. After that, sand (fine/ medium/coarse) was filled into the shear box and made to a height of 25 mm and the shear test was conducted. In practical cases, pile may be surrounded by different types of soil with different properties, different moisture content, different densities etc. In order to comply with these varying site conditions, direct shear tests were conducted on following types of soil at different conditions.

Fine, Medium & Coarse Sand at a unit weight of 1.5g/cc, in dry condition
Fine, Medium & Coarse Sand at a unit weight of 1.55g/cc, in dry condition
Fine, Medium & Coarse Sand at a unit weight of 1.5g/cc, in saturated condition
Fine, Medium & Coarse Sand at a a unit weight of 1.55g/cc, in saturated condition
Well graded sand at a unit weight of 1.5 g/cc ,in dry condition
Marine Clay only
Red Earth only

Fine, Medium & Coarse Sand at a unit weight of 1.5g/cc (Dry) on cement mortar surface
Well Graded sand at a unit weight of 1.5g/cc (Dry) on cement mortar surface
Marine Clay on cement mortar surface
Red Earth on cement mortar surface
Bentonite Layer *b/w* Fine/Medium/Coarse Sand at a unit weight of 1.5g/cc (Dry) & cement mortar surface
Bentonite Layer *b/w* Well Graded Sand & cement mortar surface
Bentonite Layer *b/w* Marine Clay & cement mortar surface
Bentonite Layer *b/w* Red Earth & cement mortar surface

After conducting shear tests for all these combinations, plots of normal stress vs shear stress were made for each case. Shear strength parameters c and ϕ were found out from these plots. Values of these shear strength parameters were analysed for studying the effect of bentonite layer at pile-soil interface.

4 Results and Discussions

4.1 Direct Shear Tests on Sand

Bearing capacity of piles can be determined by approximating the angle of friction between pile and surrounding soil, δ to the angle of shearing resistance, ϕ. Direct shear tests were conducted with fine, medium and coarse sand fractions (confirming to BIS 1498 classifications) to determine the value of ϕ [1]. Tests were conducted at a density of 1.5 g/cc in both dry and saturated conditions. Results obtained are presented in table 3. The test results showed that ϕ values were either same or tend to decrease when sample is saturated. In all the cases the variation in magnitudes of ϕ were found to be only upto three degrees. Hence it was decided to proceed with this study by testing the soil samples in dry state, keeping a dry density of 1.5 g/cc.

Table 3. Direct Shear test results on fine, medium and coarse sand

Type and soil condition	Angle of shearing resistance, ϕ(degree) for a density of 1.5 g/cc
Fine sand	
a) Dry state	29
b) Saturated State	26
Medium sand	
a)Dry state	31
b)Saturated State	28
Coarse sand	
a)Dry state	34
b)Saturated State	34

4.2 Determination of Critical Conditions for Bentonite Layer

Bentonite support fluid form a layer of filter cake on the surface of piles. For the present study, laboratory direct shear tests were conducted by manually applying a layer of bentonite over the precast cement mortar blocks. Bentonite layer could be applied at various consistencies. Hence, before proceeding to the actual tests, a critical condition for bentonite filter cake was found out.

Direct shear tests were conducted using bentonite at liquid limit water content, at water contents less than the liquid limit water content and also at water contents greater than the liquid limit water content, sandwiched between medium sand and cement mortar blocks. Results showed that critical value for angle of shearing resistance was at the liquid limit water content of bentonite as shown in table 4. Hence, it was decided to proceed with the study by choosing bentonite at liquid limit water content at cement mortar - soil interface.

Table 4. Values of angle of shearing resistance for the bentonite at different water contents sandwiched b/w medium sand and cement mortar surface

Water Content (%)	Angle of shearing resistance, ϕ (degree)
260	18.9
353	18.0
386*	**16.7**
484	23.6
543	24.2
736	24.2

* Liquid Limit of the bentonite

4.3 Direct Shear Tests with Bentonite Layer between Sand and concrete

Different combinations of sand – cement mortar surface with and without bentonite layer were selected and direct shear tests were conducted to study the variation in the value of angle of shearing resistance, ϕ. Direct shear tests were conducted for fine, medium and coarse sand, with bentonite layer manually applied at liquid limit water content on cement mortar surface and sand was filled at a density of 1.5g/cc over bentonite layer. The values of angle of shearing resistance obtained in each case are given in Table 5. To get a generalised idea of the percentage decrease in ϕ value, the direct shear tests were also done on well graded sand and its results are also tabulated(Table 5). Results showed that the angle of shearing resistance was considerably reduced due to the presence of bentonite layer at cement mortar – sand interface.

Table 5. Variation of ϕ with gradation of sand and type of interface

Sample Description	Angle of shearing resistance ,ϕ(degree) for			
	Fine Sand	Medium Sand	Coarse Sand	Well Graded Sand
sand – sand interface	29.2	30.9	33.7	32.2
sand - cement mortar block interface	28.1	29	31	29.5
Bentonite @LL b/w sand – cement mortar surface	13.1	16.7	24.6	19.8

4.4 Direct shear tests with bentonite layer between cement mortar block and marine clay/red earth

In piling sites, engineers come across different varieties of soils. Hence, in this study, shear tests were also conducted on commonly available soil types - marine clay and red earth. For conducting direct shear tests with red earth/marine clay, the soil samples had to be placed over a layer of bentonite. But it was not practically possible to compact them after placing over the bentonite layer. In order to avoid such a problem, samples of red earth/marine clay of size 60 x 60 x 12.5mm were prepared in advance by using the same mild steel mould (60x60x25 mm) and plate (60x60x12.5 mm) assembly which were used to cast cement mortar blocks. Hand compaction was applied to prepare specimens of marine clay and red earth at their natural moisture contents. It was possible to obtain samples with an average dry density of 1.6g/cc and 1.2g/cc for red earth and marine clay respectively.

It can be seen from figure 4 that, for both sand and red earth, the angle of shearing resistance values obtained in the presence of bentonite support fluid were found to be much less than those obtained for pure sand/red earth case or the case of sand/red earth – cement mortar surface combination . In the case of marine clay, variations in the values of cohesion instead of the ϕ values were analyzed. Figure 5 shows the variation of this shear strength parameter in the presence of bentonite layer, which also showed a decreasing trend, confirming the adverse effect of bentonite support fluid at pile-soil interface.

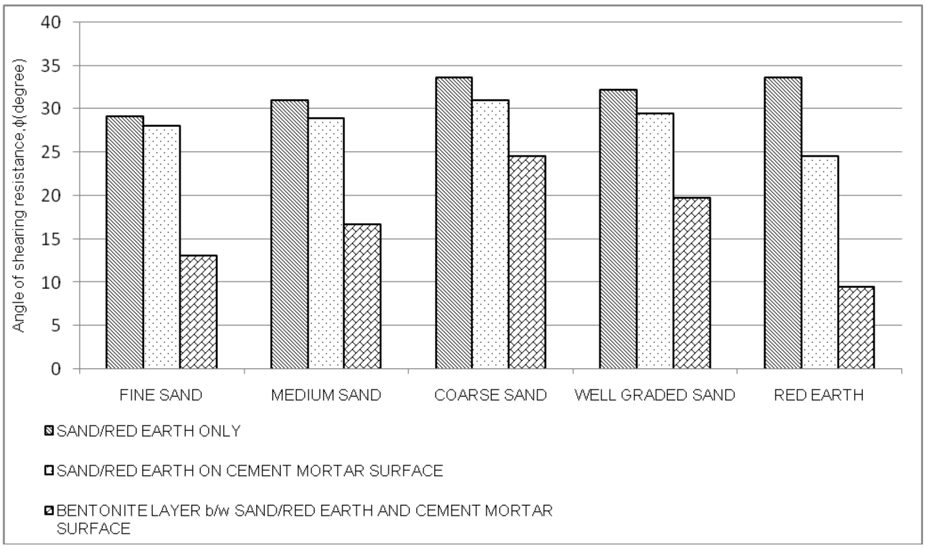

Fig. 4. Effect of type of interface on angle of shearing resistance for different soil types.

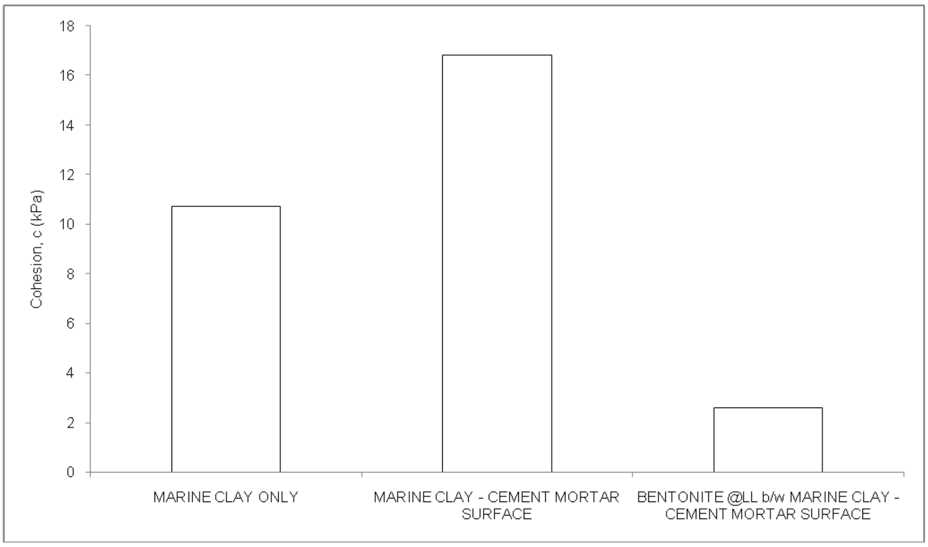

Fig. 5. Effect of type of interface on cohesion.

4.5 Effect of support fluids on frictional resistance

The main objective of the present study was to estimate the effect of bentonite support fluid on the interface frictional resistance in the case of concrete piles. The frictional resistance for piles installed in silty clayey sand is given by,

$$\text{Frictional Resistance} = \left[\sum_{i=1}^{n} K_i P_{Di} \tan\delta\right] A_{si} + \sum_{i=1}^{n} \alpha_i C_i A_{si}$$

where, K - The lateral earth pressure coefficient.

P_D - The effective overburden pressure at pile toe.

tan δ - The coefficient of friction between soil and pile surface.

A_s - The effective surface area of the pile in contact.

D - Stem diameter of the pile.

γ- Effective unit weight of soil at pile toe.

δ - Angle of wall friction between pile and the surrounding soil.

α - The adhesion or reduction factor.

C_i - The average undrained cohesion for a particular layer.

Values of coefficient of friction depend on the type of soil and pile material. McCarthy(1982) reports values from 0.2 to 0.45 depending on the roughness of pile surface. Indian standards recommend angle of wall friction, δ = ϕ, where ϕ is the angle of shearing resistance [2].

For pilings assisted by support fluids, while calculating the skin friction, approximation of δ = ϕ is to be relooked, considering the results of the laboratory investigations, discussed in the previous sections. Since, at the sand-concrete interface, support fluids form a thin layer, the effect of these support fluids on interface frictional resistance has to be considered. For this purpose, a pile of 60 cm diameter and 50m length (very common in Cochin area) was assumed with surrounding soil having a bulk unit weight of 18 kN/m^3. Values of K was taken as 1, α = 0.3 and effective overburden pressure was taken for a depth of 20 times diameter of the pile. Variation in frictional resistance for piles in sand with bentonite slurry is presented in table 6 and that of red earth and marine clay in presence of bentonite is presented in table 7.

Table 6. Variation of frictional resistance for pile in sand

Sample Description	Frictional Resistance(kN)			
	Fine Sand	Medium Sand	Coarse Sand	Well Graded Sand
Without support fluid	1159	1203	1304	1228
With support fluid	505	651	994	781

Table 7. Variation of frictional resistance for pile in red earth or marine clay.

Sample description	Frictional Resistance(kN)	
	Red Earth	Marine Clay
Without support fluid	992	113
With support fluid	361	17

5 Conclusions

While calculating the ultimate capacity of bored/driven piles in cohesionless soils, value of angle of wall friction, δ is the requisite. But as per Indian Standard recommendations, this value is approximated to angle of shearing resistance, ϕ of the soil surrounding the pile. A set of direct shear tests has been carried out in order to study the effects of bentonite support fluid on the pile-soil interface frictional resistance. The results indicated that bentonite layer will adversely affect the interface frictional resistance. From the study, it is observed that

1. The value of δ at pile – sand interface(when bentonite layer is not considered) reduces upto 28% from the actual ϕ value of sand surrounding the pile.
2. The value of δ at pile – sand interface (when bentonite layer is considered) reduces upto 72% from the actual ϕ value of sand surrounding the pile.

On the other hand, in case of bored/driven piles in cohesive soils, value of shear strength parameter, c is the requisite. From the study it was found that

1. The value of cohesion, c for the case of bentonite layer at pile – clay interface is found to be about 75% less, compared to the case when the effect of bentonite layer was not considered.

Similarly it was observed that with the presence of bentonite slurry, frictional resistance decreased by 24 to 56% in case of sand-concrete interface, 64% in case of red earth-concrete interface and 84% in case of marine clay-concrete interface. This reduction in values will ultimately affects the load carrying capacity of piles and hence the foundation performance. It is hoped that these findings will be very much beneficial for engineers while estimating the pile capacity.

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