EFFECT OF FILTERCAKE ON INTERFACIAL FRICTION –AN EXPERIMENTAL STUDY

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ABSTRACT: Bored piles are normally formed by advancing the boreholes by Direct Mud Circulation (DMC) method. The filtercake thus formed acts as an interfacial layer between the concrete and the soil, which affects the pile capacity. The characteristics of bentonite cake formation and its influence on the interfacial friction has been studied. The parameters such as specific gravity of slurry and polymer are varied to understand the characteristics. The thickness of filtercake has been estimated from the model tests. From the load-settlement response the value of ‘K tan δ’ is back calculated and compared with model piles without bentonite circulation.

INTRODUCTION
When the soil near the ground is not having adequate strength to bear heavy loads, bored piles of larger diameters are preferred to resist the loads. Among the different methods, advancing the bore hole adopting Direct Mud Circulation (DMC) technique using bentonite as drilling mud, then installing a reinforcement cage and concreting with tremie pipe by displacing the slurry is widely practiced method. The bore hole is filled with bentonite slurry (drill mud) during construction to prevent the collapse of side walls of bore hole as well as heaving at its base. A layer of filter cake formed due to penetration of slurry in to the walls acts as an interfacial layer between the concrete and the soil, which affects the load resisting ability of pile. Hence the drilling system requires alternate drilling fluid which stabilises the hole as well as not affecting surface friction or the slurry to be improved so that the thickness of filter cake is reduced.

The project is intended to study and understand the characteristics of bentonite filter cake formation and its influence on the interfacial friction between pile and soil. Two different materials are chosen for this study. One is bentonite mud and the other is polyacrylamide. Tests are carried out by varying the specific gravity of slurry and friction factor between pile and bentonite is estimated from the pullout test.

LITERATURE REVIEW
Numerous researchers have worked on the rheological properties of different bentonite suspension. In suspension the bentonite particles become oriented with negative faces in association with the positive edges to form a three dimensional ‘house of cards’ structure. This structure is relatively weak and gets broken when it stirred and the system becomes more fluid. When the suspension is at rest, the broken bonds are reformed and it gels once again. This property of the suspension is called thixotropy and it increases with increase in concentration. This quality of bentonite suspension is very useful for stabilizing the bore hole made for installation of bored piles. In most of the bored pile installations, sodium bentonite is used as a drilling fluid. At relatively low bentonite concentration, the rheology approached to pseudo-plastic behavior and the response follows Power law model. It has been observed that for higher polymer concentrations, a considerable reduction in fluid loss and a slight decrease in filtration cake were observed [1].

High filtration time (T_f) and high filtration pressure (h_f) produce thicker and more compressible filtercakes yielding lower final stresses, also final stresses are higher for larger diameter holes [2]. Longer construction time reduces the shaft carrying capacity of bored piles constructed under slurry and the major portion of the degradation occurs with in the first 24 hours period [3]. For bored piles in sand, the soil pressure coefficients decrease with the depth, also there seems to be no difference in side friction for piles in tension and compression and the frictional angle δ for uncased boring is equal to the friction angle φ of the soil [4]. The polymer slurry of higher concentration apparently stabilizes the borehole very well and was either scoured by the raising mortar during concreting or later reacted with the alumino silicates in the cement in the mortar to yield sound interfaces. The polymer slurries were not as sensitive to time of exposure or to common contaminants as were the mineral slurries [5].

The studies suggest that interfacial friction value (β = K tan δ) found to vary widely between 0.1 and 2.66. The attempts are made in bored cast in-situ piles by application of cement grout at the bottom and sides to increase the adhesion factor in China and South Asian countries and succeeded.

EXPERIMENTAL PROCEDURE
For Determination of Cake Thickness
A setup is fabricated to determine the cake thickness as shown in Fig 1. The tank, sample retainer and collection chamber arrangement made, in which provisions are made to collect permeating fluid at any time during the test.
The sample was prepared by filling the sand in sampler tube, so as to achieve the density of 1.61 gm/cc. The slurry of required viscosity was prepared and filled in the slurry tank without disturbing the sample. The slurry in the tank was kept for 4 hrs and allowed to permeate through vertical and horizontal samples. At the end of the test, samples were carefully removed from the sample retainer. The sample divided into parts and each part analysed for the presence of bentonite particle and the depth of penetration is observed from the analysis.

**Formation of model pile**
The model pile of diameter 75mm and length of 400mm was fabricated in the test tank. The provision was given in the tank to saturate the medium from bottom to top. The water table was monitored through the transparent stand pipe provided at the diagonally opposite corner of tank. The slurry is maintained in the pile hole for 4 hrs to allow the slurry to penetrate in to the sand and to form the filter cake. The model pile was cast in the test tank using concrete of grade M30, and the pull out test on the model pile was carried out after 7 days of curing to determine the load versus displacement relationship.

**Preparation of Bentonite Slurry**
The sodium based bentonite belongs to the montmorillonite group clay minerals, selected for this research work. The required quantity of oven dried bentonite was taken in advance and mixed with water and allowed it to hydrate fully. The quantity of bentonite to achieve the required density was calculated using the relationship between specific gravity of bentonite and slurry [6].

**PERFORMANCE OF DIFFERENT DRILLING FLUID**
The preliminary test results on bentonite sample shows that the values of specific gravity, liquid limit, plastic limit, shrinkage limit, plasticity index and free swell are 2.76, 403%, 47%, 8%, 356, 2.08 and 1500% respectively. The sand content, silt content and clay content in the bentonite sample are 2.10%, 54.90% and 43.00% respectively.

The medium chosen for the study is uniformly graded Palar river sand. Its D_{10} size is 0.28mm with fine, medium and coarse sand fractions of 21%, 74% and 4% respectively. The chosen sand is classified as poorly graded sand (SP) as per Unified classification system. The study conducted by keeping the density of the sand medium at 1.60gm/cc for all the tests. Direct shear test is also conducted on sand at the unit weight of 1.6 gm/cc, the \( \phi \) value thus obtained is 36°.

**Flow Response of Drilling Fluid**
The viscosity of the drilling fluid is an important property which governs the carrying capacity by not allowing the particle settlement during the advancement of bore hole. This property is analysed for the bentonite slurry and polymer solution using Marsh funnel commonly called as “Slurry funnel”. This is widely used in the construction industry due to its simplicity.

**Bentonite Slurry**
The viscosity of bentonite slurry of various specific gravity of suspension (between 1.01 and 1.08) is measured in the Marsh funnel. The relation between specific gravity versus time is shown in Fig. 2 and it can be seen that Marsh cone viscosity increases with specific gravity of bentonite slurry and it increases exponentially beyond the specific gravity of 1.04. The Marsh cone viscosity of bentonite slurry is less than 35 seconds for the specific gravity of suspension between 1.01 and 1.08. In general low specific gravity will not offer adequate strength and high specific gravity has a problem of cake formation in addition to displacement of slurry. In this study specific gravity of suspension of 1.05, which has Marsh cone viscosity of 29s has been adopted in all other tests.

**Polyacrylamide Solution**
The Marsh funnel tests are conducted for the polyacrylamide solution by varying concentration from 0.5 to 1.3gm/l with an increment of 0.1gm/l. The results thus obtained are presented in Fig. 3. It is surprising to note that the marsh cone viscosity values are more than 35s for the tested concentrations of polyacrylamide solution and are
Effect of filtercake on interfacial friction – Experimental study.

higher than the values of bentonite slurry. Marsh cone viscosity increases exponentially with increase in polyacrylamide concentration as observed in the case of bentonite solution.

Determination of Filtercake Thickness

**Bentonite Slurry**

To know filtercake formation, series of tests are conducted in the specially fabricated test setup for the bentonite slurries of specific gravity 1.03, 1.05 and 1.06. The sand specimens (horizontal and vertical samples) are extracted from the sampler and are divided into parts. Each part of the sample is analysed for the presence of bentonite particle by wet sieve method. The relation between distance from the slurry contact face and percentage of bentonite present in each sample is plotted and the depth of filtercake thickness is determined from the plot. This observation confirms to the findings of Huder [7]. The cake thickness increases as the slurry specific gravity increases. For the slurry of specific gravity is 1.03, 1.05 and 1.06, the filtercake thickness is 7, 10 and 13mm respectively.

![Fig. 3 Relation between polyacrylamide concentrations to Marsh flow](image)

**Polyacrylamide Solution**

It is observed that no filtercake is formed in the sample tested using polyacrylamide solution as drilling fluid. Hence the fluid loss through the sample is determined by measuring the flow of liquid at periodical interval. The rate of fluid loss is high at the initial stage and reduces to a constant rate of flow for 0.50, 0.75, and 1.0gm/l concentration of polyacrylamide. The rate of flow for the horizontal sample reduces from a high value at the start of the test (33.33ml/min) and becomes constant (18.83ml/min) as the time increases for 0.5gm/l concentration. Similar trend was seen in the vertical sample also, but the flow rates are slightly less, when compared with the respective concentrations. The rate of flow of the experiment is 5.33 and 5.20ml/min for the concentrations of 0.75 and 1.0gm/l respectively for horizontal sample. However the flow rate reduces to 0.76 and 0.05ml/min after a duration of two hours for the concentration of 0.75 and 1.0gm/l respectively. There is no significant difference in flow rate between horizontal and vertical specimens for the concentration of 0.75 and 1.0gm/l. As the concentration increases fluid loss decreases.

The sand samples ejected from the sampler after permeation of polyacrylamide solution of known concentration (0.5, 0.75, and 1.0gm/l) for a specific period were examined. The ejected sand sample retained its shape, but no evidence of filtercake formation. The observation on samples indicated that the polyacrylamide solution with concentration of 0.75 and 1.0gm/l has the ability to stabilize the sand on permeation whereas the concentration of 0.5gm/l fails to retain the shape of sand sample. The polyacrylamide material on permeation fills the voids and forms a gel substance which acts as bond to the particles. From the observations made it is obvious that the polyacrylamide concentration of 0.5gm/l is not suitable for the drilling purpose because of its high fluid loss leading to danger of contaminating the ground water and poor ability in stabilizing the sand.

**MODEL PILE UNDER PULLOUT LOAD**

The model pile was subjected to pullout load to analyse the frictional capacity alone. The frictional capacity without slurry interface has been kept as base to compare the results of model pile with bentonite slurry interface.

**Estimation of Frictional Factor “K tan δ”**

Chaudhuri and Symons [8] described the Eq. 1 in the dimensionless form and related with the frictional factor and the ratio of length to diameter of model pile.

\[ \frac{P_u}{A L \gamma'} = 2K \tan \left( \frac{L}{d} \right) \]

where, \( P_u \) = ultimate uplift resistance of pile, \( A \) = cross sectional area of pile \( (= \pi d^2 / 4) \), \( K \) = coefficient of earth pressure, \( \delta \) = soil-pile interface friction angle, \( \gamma' \) = unit weight of sand, \( L \) = length of model pile, and \( d \) = diameter of pile. The results of this study are compared with the predicted values of Meyerhof [9], Hansen [10], Chaudhuri and Symons [8] and also for the values assuming \( K = K_p \). Further the value of \( K \) obtained by assuming \( \delta = \phi \) is compared with the previous studies.

The load-displacement relationship obtained from the pullout test conducted on model pile of 75mm diameter and 400mm long without slurry interface and also for other slurry interface is shown in Fig. 4. It is evident that the resistance of pile against pullout increases rapidly with displacement. However the rate of increase of resistance decreased rapidly after the pullout displacement of 1mm. At pile displacement of 2.5mm the pile offered almost its ultimate resistance and there after the displacement of pile increases rapidly. Thus the load-displacement curve exhibited asymptotic response, which is similar to the stress-strain of soil recognized by Kondner [11].
The “K tan δ” values obtained using Eq. 1 are 2.61, 2.16 and 2.36 for interfaces without slurry, with bentonite slurry and with polyacrylamide solution respectively. The “K tan δ” values of interface with bentonite slurry and polyacrylamide solution are less by 17.5% and 9.5% respectively while comparing with the value obtained without slurry. The ‘K’ value determined by taking δ = φ are also compared with work of Meyerhof [9] and the values thus obtained are higher and closer to Kp value. The lateral earth pressure coefficient (K) obtained for various slurry interface on the assumption of I G found to vary between 2.97 and 3.05 and these values are very close to passive earth pressure coefficient (Kp) of sand in which tests conducted.

REFERENCES

CONCLUSIONS
The viscosity increases exponentially with increase in specific gravity of bentonite and polyacrylamide solution. The rate of flow of polycrylamide solution reduces with increase in time, and for the concentration of 0.5gm/l the rate of flow is six times higher than other two concentrations (0.75 and 1.0gm/l). Low concentration (below 0.5gm/l) of polycrylamide must be avoided even though it satisfies the marsh cone viscosity as per BIS specification. The load-displacement relationship of model pile for different interface layers is identical and it typifies rectangular hyperbolic relation. The frictional factor “K tan δ” for interface without slurry is 2.61 and it reduces to 2.16 due to bentonite slurry interface, which is less by 17.5%.

Fig. 4 Relation between load and displacement for all the slurry interface and without slurry interface

Table 1 Comparison of pullout load with various researchers for (L/d)= 5.33

<table>
<thead>
<tr>
<th>Methods</th>
<th>K</th>
<th>Pp/(Ay'L)</th>
<th>Pp (kN)</th>
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<tbody>
<tr>
<td>Meyerhof (1973)</td>
<td>1.60</td>
<td>11.58</td>
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<tr>
<td>Hansen (1968)</td>
<td>0.39</td>
<td>2.85</td>
<td>0.080</td>
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<tr>
<td>Chaudhuri and Symons (1983)</td>
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<td>7.55</td>
<td>0.213</td>
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<tr>
<td>Kp</td>
<td>3.85</td>
<td>27.96</td>
<td>0.791</td>
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<tr>
<td>Present study</td>
<td>3.60</td>
<td>27.87</td>
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