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CHANGES IN PROPERTIES OF CLAY SURROUNDING CAST IN-SITU PILES

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Abstract: For piles in clay soils, the major contribution to working load capacity is from the shaft resistance, which is influenced by the types of piles used and construction methodology adopted. In the case of preformed piles, the time-related response relates to changes in pore water pressure. However, in the case of cast-in-situ concrete piles it is anticipated that changes in soil chemistry due to migration of ions from the concrete would have an effect on soil/pile interaction. A laboratory-scale test conducted to investigate change in soil chemistry with time and its impact on load carrying capacity of cast in-situ piles in Oxford clay showed that there was a short-term increase in moisture content of soil adjacent to the piles. It also showed that there was an increase in both hydroxyl and calcium ion concentration. These also affected adhesion factor, which increased with time to a limiting value.

1. INTRODUCTION

Piles of various types and construction are normally used to transfer building load to more competent soils at depth. The various forms of piles include driven and cast in-place piles.

For piles in clay soils, the major contribution to working load capacity is from the shaft resistance, which is influenced by the types of piles used and the construction methodology adopted. In the case of performed piles, the time-dependent response relates to changes in pore water pressure. However, in the case of cast in-situ concrete piles, it is anticipated that changes in soil chemistry due to migration of ions from the concrete would have an effect on soil/pile interaction. Investigations on soil-to-structure interfaces were carried out by researchers such as POTYONDY [10], PETERSON et al. [9], LEMOS and VAUGHAN [6]. The results show that the skin resistance increases with the increasing of normal load. This is due to the variation of density of the soil with the normal load. Also, the increment of normal load would cause significant change in saturation and pore pressures, while contact area will experience expulsion of air, giving more contact to the surface area. This leads to the four major factors, i.e. moisture content of soils, roughness of surface, composition of soils and intensity of normal load, which determine skin friction.

An investigation was conducted to assess the extent of changes in the physical and chemical nature of the soil and its effect on the behaviour of model piles.

2. MATERIALS AND METHODOLOGY

Soil used in the study was characterised and its engineering properties were determined. Following this, the strength of soil/concrete, based of fresh concrete placed on a bed of soil, was determined. Finally, model cast in-situ piles were made in a bed of soil. Piles were tested for failure at the range of time intervals and changes in moisture content, and ion content of the soil was measured along lines radiating from the piles at a range of depths.

2.1. SOILS

Oxford clay, obtained from a brick quarry, was used in this investigation. Its properties are given in table 1 (LEE [7]).

Table 1

Properties of Oxford clay (LEE [7])

Properties	Oxford clay
Index properties	
Plastic limit	30%
Liquid limit	61%
Plasticity index	31%
Optimum moisture content (%)	24.5%
Maximum dry density	1.465 (g/cm^3)
φ'_{peak}	21.2°
φ'_{crit}	
Specific gravity	19.4°
	2.62 ± 0.02
pH	7.15 ± 0.05
Calcium ion content	$(2.48 \pm 0.05) \cdot 10^2$ (ppm)

2.2. CONCRETE

Concrete comprising Portland cement (400 kg/m^3) and aggregate with maximum particle size of 6 mm was used in this study. It had slump of 75 mm and an average 28-day compressive strength was 30 N/mm^2. The composition of concrete is given in table 2. All the tests on concrete were carried out in accordance with BS1881:Part 102:1983.

Table 2

Constituents of concrete

Constituent	Quantity (kg/m^3)
Water	460
Cement	299
Water/cement	0.65
Fine aggregate	828.9
Coarse aggregate	1013.1

2.3. TEST APPARATUS AND METHODOLOGY

Oxford clay with a moisture content of 30% (at plastic limit) was stored for 24 hours to allow soil particles to hydrate before it was compacted in the test cell at a dry density of (1460 kg/m^3). The test cell comprised a plastic tubular cylinder of 10-mm wall thickness, 395-mm diameter and 400-mm depth. The bottom plate was 10-mm thick and it was bolted to the lower collar. Soil was compacted to a depth of mm in the mould.

An impermeable plastic sheet was placed at the top of the clay, followed by a solid disc. A circular rubber cell that could be inflated with air was then placed on the disc layer before the upper plate was bolted onto the cell. The pneumatic tyre was inflated to 70 kPa. This stress simulates an arbitrary depth of approximately 3.6 m corresponding to the site.

After the clay bed had cured for a month, its moisture content was measured at various locations and it was found to range between 23.5% and 25%; the narrow range confirmed the uniformity of the deposit. Holes of both 133-mm and 75-mm diameters were augered to the full depth of the soil deposit. Fresh concrete was then placed in the holes such that the bottom 70 mm remained avoid. This ensured that load transfer to the soils would be entirely through the side friction.

Once the concrete was poured, a thick Perspex plate was placed on the upper surface. An inflatable rubber ring was placed on this disc and the chamber ring was bolted on. The rubber ring was inflated at 70 kPa and the specimens were allowed to cure for the periods ranging from 1 to 10 months. Eight piles were tested in this study.

At the end of the curing period, the capacity of the piles was determined by conducting a constant rate penetration test. Pile was loaded at a rate of 0.01 mm/min up to pile deformation of at least 10% of the pile diameter. Following the load test, the soil from the test chamber was excavated in layers. Samples from the four quadrants were at 10-mm interval from the pile wall to the test cylinder. Samples were taken at 50-mm vertical interval. The tests conducted on the recovered samples are listed in table 3.

Table 3

Specimen test of a radial distance

Determinant	Standard
Moisture content	BS 1377 : 1990
Plastic limit	BS1377 : part 2 : 1990
Liquid limit	BS 1377 : part 2 : 1990
pH	BS 1377 : part 3 : 1990
Calcium ion content	BS 1324 : part 2 : 1990

3. RESULTS AND DISCUSSION

3.1. LOADING TESTS

The load/axial displacement relationships of 133-mm piles after curing period ranging from one month to ten months are shown in figure 1. It was anticipated that there would not be a significant change in strength as concrete achieves most of it strength in the first 28 days and so the soil–pile interaction was not expected to change significantly over this period. Test results, however, show that there was an approximately 15% increase in the capacity of the pile. Time-related load tests were also carried out for 75 mm for one-month and five-month curing. Peak load/curing period relationship for both the piles, shown in figure 2, indicates an increasing trend in capacity with time.

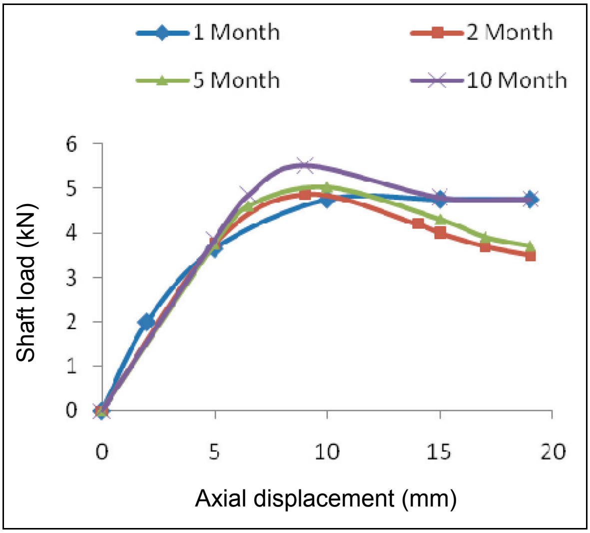

Fig. 1. Load–settlement curves for 133-mm diameter pile for different curing durations

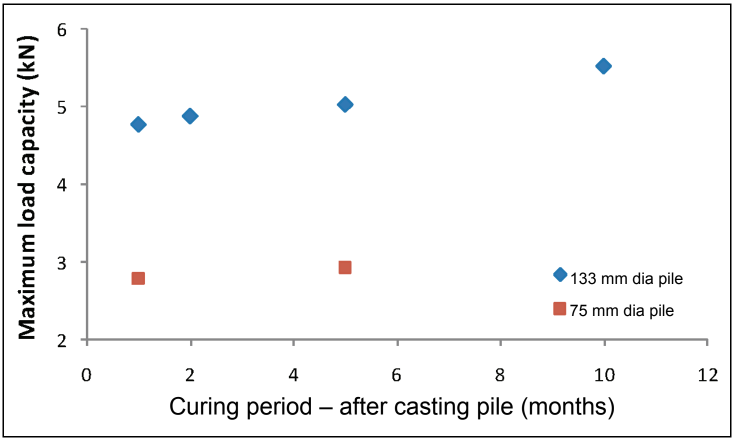

Fig. 2. Variation of ultimate shaft load with time

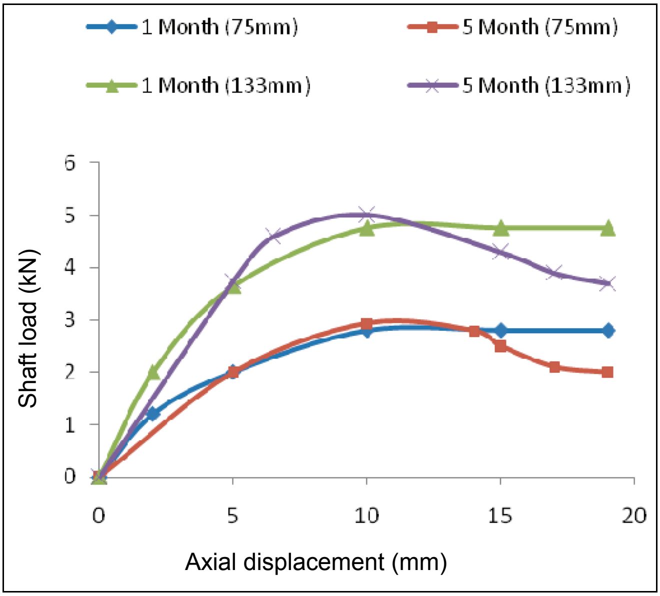

Fig. 3. Load–settlement curves for 75-mm and 133-mm diameter piles
for different curing duration

Load–displacement capacities of both 75-mm and 133-mm diameter piles at one-month and five-month curing after piles were cast are shown in figure 3. For each pile diameter it is apparent that a distinct peak load is observable for 5-month curing period. This type of behaviour was also noted in the results shown in figure 1. This suggests that there was a change in the properties of the soil at the soil–pile interface.

3.2. MOISTURE CONTENT

Variation in moisture content with the distance of up to about 130 mm from the edge of the pile is shown in figure 4. Datum values obtained from the cured specimens of soil compacted and the specimens cured in the same way as those in which piles were constructed are also shown in figure 4. Results indicate that moisture content of the soil is affected to a diameter of about 50 mm from the pile edge. Change in moisture in terms of datum values is shown in figure 5. One month after casting the moisture content of piles with 10 mm shaft was as high as about 4%. After 10 months the

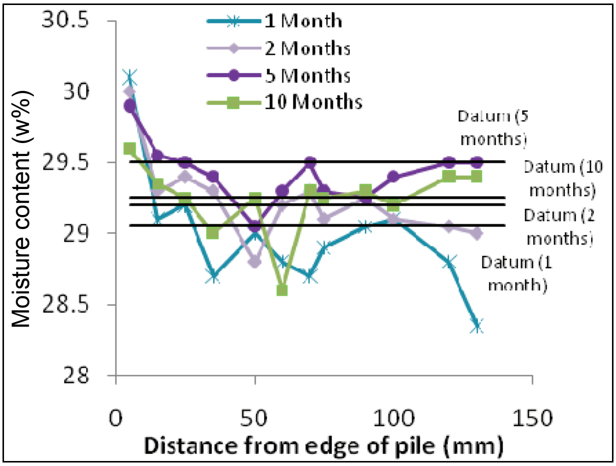

Fig. 4. Variation of moisture content with distance from edge of pile

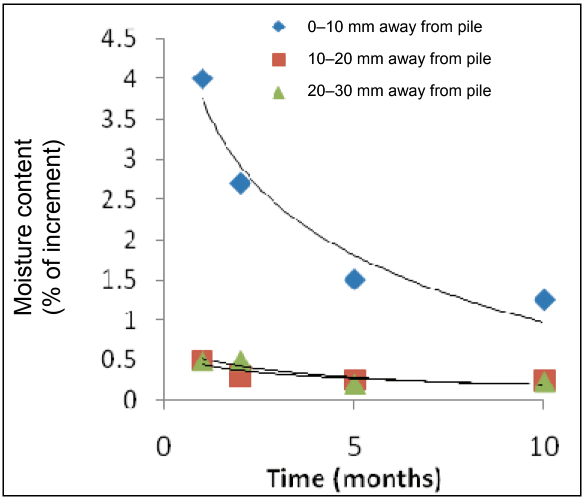

Fig. 5. Variation of moisture content with time

increase is only by about 1.5%. Beyond about 10 mm, after one month, the moisture content is only by about 0.5% above the datum value. With time the moisture content tends towards the datum values. Skempton (1959) suggested that a 1%-change in moisture content can produce the strength variation of clay as great as 20%. Hence, the gradual reduction of moisture content at the vicinity of the pile results in an increase in pile capacity as noted in the results shown in figures 1 and 2.

3.3. ATTERBERG LIMITS

The effect of fresh concrete on the plasticity of the surrounding clay was investigated through examination of changes in both liquid and plastic limits of soil surrounding the pile. The results of liquid limit (LL) and plastic limit (PL) tests are shown in figures 6 and 7, respectively, for curing periods ranging from one month to ten months. These results were similar to those of VENKATA [13], BARKER et al. [3] and LARSON et al. [5]. The decreasing rates of PL and LL with distance indicate that cation-exchange capacity does occur due to the presence of calcium ions where the higher valence cations replaces those of a lower valence, thus altering the index properties of Oxford clay. This reduces the thickness of the diffusion double layer forming edge-to-edge contact imposing a positive impact on pile loading capacity. The changes in index properties are again limited to a distance of 75 mm from the pile edge and changes continue to occur to the 10-month monitoring period as shown in figure 8.

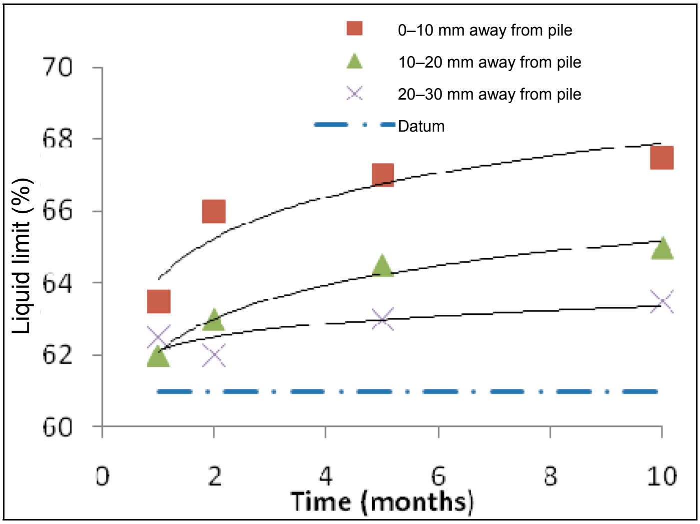

Fig. 6. Variation of liquid limit with time for 133-mm diameter pile

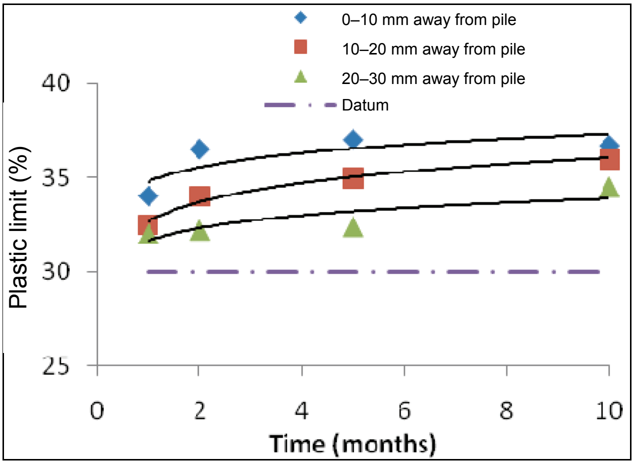

Fig. 7. Variation of plastic limit with time for 133-mm diameter pile

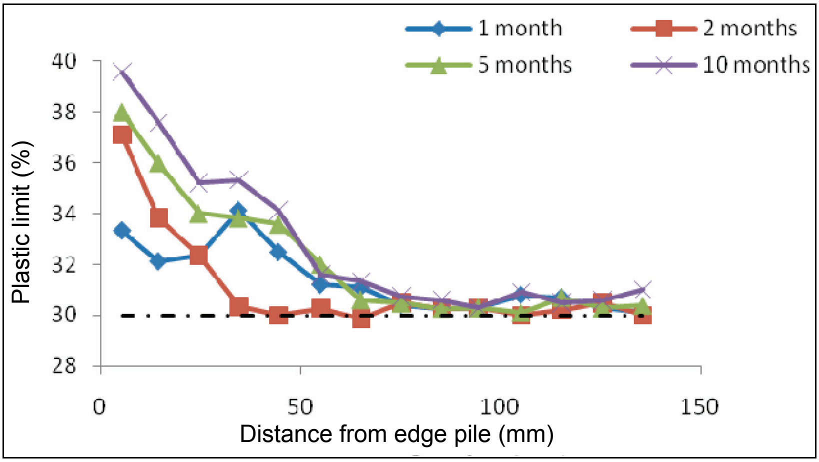

Fig. 8. Variation of plastic limit with time for 133-mm diameter pile

3.4. pH CHANGE

Changes in pH continued to occur up the 10-month monitoring period and the highest pH values recorded (of about 8.5) were adjacent to the pile (see figure 9). pH levels remained high (about 8.5) throughout the monitoring period. However, within about 20 mm pH reverted to the datum values. The results obtained from the 75-mm diameter piles had a similar trend to that of the 133-mm diameter piles with pH values lower by approximately 3%. The limited distance of elevated pH was partly caused by the hydraulic gradient, which encourages hydraulic ions migration. This phenomenon may also be attributed to the buffering effect of the soil where hydroxyl ions migrate through establishing a steady-state condition.

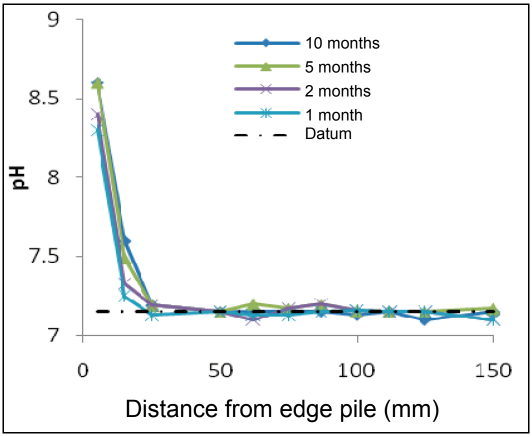

Fig. 9. Variation of pH with distance from edge of pile with time for 133-mm diameter pile

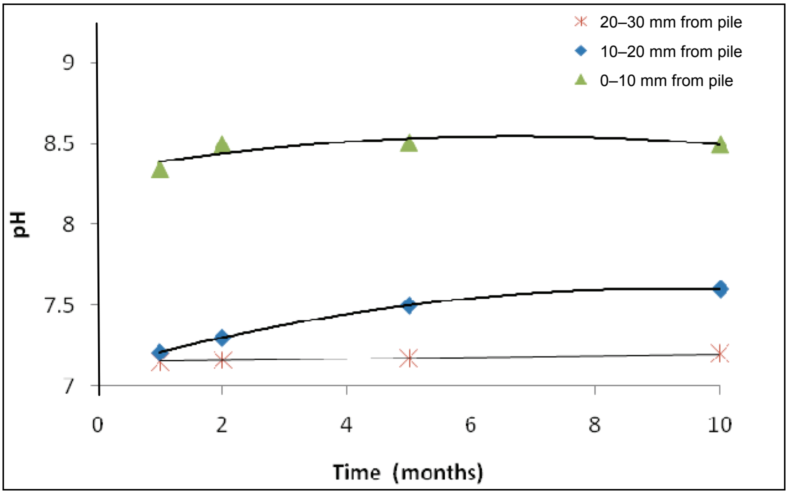

Fig. 10. Variation of pH with time at a range of distance from pile edge

3.5. CALCIUM ION CONTENT

Lime is released from the cement in concrete used in the construction of bored piles. In addition to this, hydroxyl ions, which increase pH of the surrounding soil, are also released. In alkaline medium, silica and alumina in the clay start to react with the calcium ions to form soil strengthening bonds.

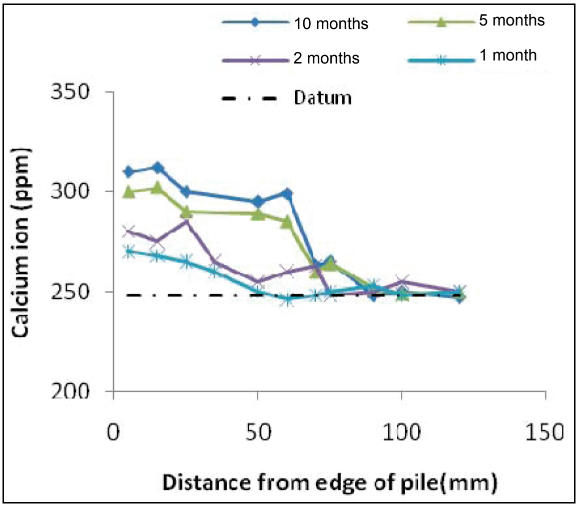

Fig. 11. Variation of calcium ion content from edge of pile with time for 133-mm diameter pile

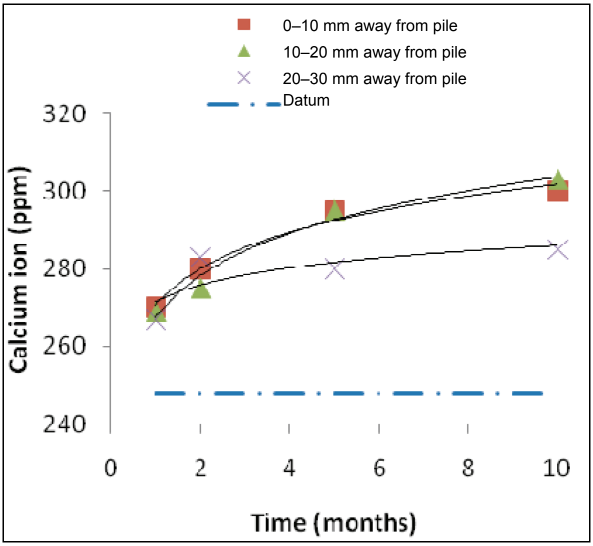

Fig. 12. Variation of calcium ion content with time

Results, shown in figure 11, indicate that calcium ions extend the range of about 80 mm from the pile periphery in 10 months. They also show that they occur at this distance after about 2 months, but no increase was observed beyond 80 mm as is shown in figure 11. For the 75-mm diameter piles similar patterns were observed at a lower scale. Based on the studies by LARSON et al. [5], Löfroth, and BARKER et al.

[2] it is shown that maximum distance of calcium ion migration from the edge of the pile varied from 50 mm to 75 mm in 10 months. This observation indicates that diffusion (gradient in chemical concentration) is the dominant flow mechanism causing the migration of Ca^{2+} ions. BARKER et al. [2] report that the rate and degree of migration depend on clay mineralogy, water content and also hydraulic gradient. Some researchers have also attributed the increase in calcium ion migration to the increment of shrinkage and plastic limits. From a physical point of view, lime in the form of calcium oxide would after the surface smoothness of the pile, hence increasing the shear strength between piles and the surrounding soil. Variation in lime content with time within about 30 mm of pile shaft is shown in figure 12. Results suggest that an increase in calcium ions is likely to be continued for some time beyond the 10-month monitoring period.

BARKER et al. [3] report that ion migration is independent of hydraulic transport and that calcium ion migrates over a greater distance compared to hydroxide ion. The finding of this study confirms this as changes in moisture content are limited to about 30 mm from the pile wall and calcium ions seemed to migrate 4 times the distance of the hydroxyl ions.

3.6. SHAFT RESISTANCE OF BORED PILES

Load test data was analysed in terms of the shaft adhesion factor β and its variation in respect to calcium ion concentration and pH which is shown in figures 13 and 14, respectively. An increase in the value of β would result in an increase in capacity of a pile.

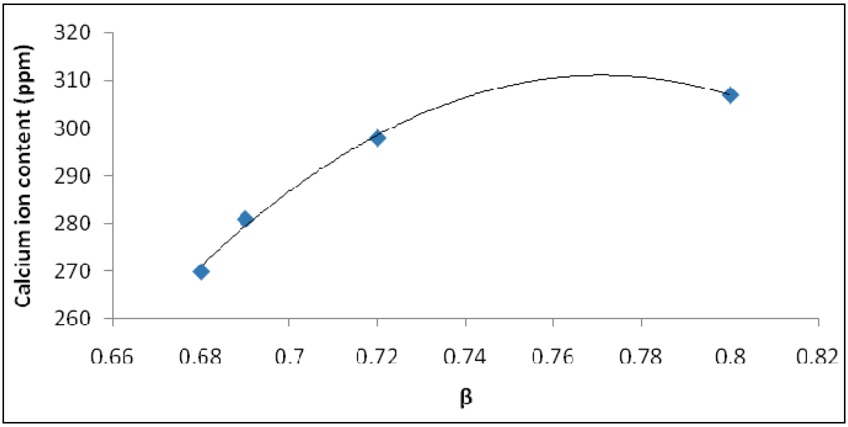

Fig. 13. Variation of calcium ion with β

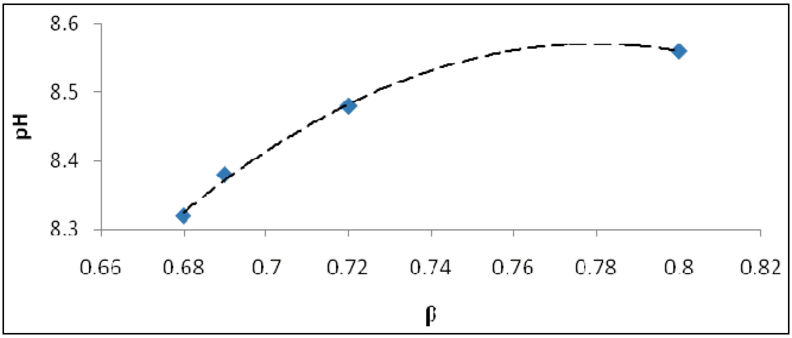

Fig. 14. Variation of calcium ion with β

The non-linear relationships between the calcium ion concentration and β as well as between pH and β show that chemistry is one of the main criteria influencing the shaft resistance of bored piles. As the effect of chemical changes, a surrounding soil appears to be a function of time, changes in β would be the function of changes in pH and calcium ion content. Change in β with time seems to confirm this (see figure 15). LEE [7] has shown that in the case of cast in-situ piles in Oxford, the factor β of clay can increase by about 15%. This may be partly the reason for the observation made by WHITAKER and COOKE [14] on cast in-situ piles in London clay, which exhibited an increase of 13% over the period of 15 to 62 weeks.

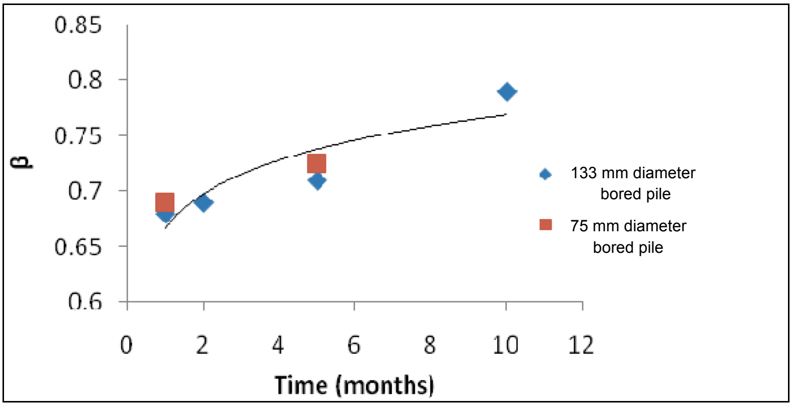

Fig. 15. Variation of β with time

4. CONCLUSION

From this investigation into the effect of fresh concrete on the surrounding soil, the following conclusions are drawn:

An increase in pile moisture content due to concrete was extended to only about 4 mm from its wall and within about 10 months it was tending towards datum moisture levels.

The concentrations of both hydroxyl ions and calcium ions increased in the soil surrounding the piles and calcium ions migrated to a distance of about 80 mm, i.e. of about 4 times the distance migrated by the hydroxyl ions. These findings confirm those of other researchers.

Changes in chemistry of the soil may be reflected in the changes in the adhesion factor of the piles. An increase in adhesion factor may occur due to migration of ions from concrete to soil.

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