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Full Length Research Paper

Stabilization of peat soil by soil-column technique and settlement of the group columns

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A field model study was carried out in Klang area of Selengor Dharul Ehsan, Malaysia to observe the settlement of stabilized group peat columns. Peat soil exhibits very low bearing capacity and this soil is not suitable for constructing embankment, highway, building or any other load bearing engineering structure. Large areas of land all over the world are covered by problematic peat soils. The growing demand of space to accommodate new buildings and infrastructures has increased the utilization of soft ground such as peatland. Two sets of test group columns were constructed to stabilize tropical peat by *in-situ* soil-column with mixing auger and Prebored-premixed method using high setting PFA cement, calcium chloride and siliceous sand as binders. Static load test was performed to observe the settlement of group columns after 28 days of curing time. Computer modelling using PLAXIS software was conducted to compare the load vs. settlement data of group columns. From this study 13.5 mm settlement was observed for the group columns installed by hand mixing and 17.5 mm settlement was found for the mixing auger method. This is due to the fact that proper mixing plays an important role for the achievement of high load carrying capacity of stabilized column.

Key words: Stabilization, binder, bearing capacity, field experiment, PFA cements, sand, mixing auger, prebored-premixed, static load test, computer modelling.

INTRODUCTION

One major problem associates with peat soil is its low bearing capacity. The words ‘bearing capacity’ and ‘peatland’ do not immediately sit well together. Peat in its natural state consists of water and decomposing plant fragments with virtually no measurable bearing strength (Hashim and Islam, 2008a). From earlier studies, it was revealed that peat bearing capacity is very low and this soil is apparently influenced by the water table in the presence of subsurface woody debries (Ooi, 1982; Ismail, 1984; Andriesse, 1988). This type of problematic soil has long term settlement value when subjected to moderate load increase (Jarret, 1995). Ground improvement work is often required to build any type of load bearing structure on soft peat soil.

Traditionally, excavation-displacement or replacement, preloading and vertical drains, stone columns, RCC piles, light weight foundation system, deep soil stabilization methods are used in construction industries for ground improvement in peat soil (Duraisamy et al., 2007; Edil, 2003). Nowadays, deep soil stabilization method is proven to be more economical and requires minimum time. The essential features of deep soil stabilization are columns of stabilized materials that are formed by mixing the soil in place with a ‘binder’ and the interaction of the binder with the soft soils leads to a material, which has better engineering properties than the original soil (Hebib and Farell, 2003).

Research findings indicated that the engineering properties of peat soil can be improved by including binders such as ordinary Portland and rapid setting PFA cement, ground granulated furnace slag, bentonite etc. (Ahnberg, 2006, Hashim and Islam, 2008b; Sing et al., 2009). One of the major requirements for the safe and economic design of a foundation is the determination of ultimate bearing capacity. This is a maximum load that can be applied to subgrade soil from the foundation without the occurrence of shear or punching failure, keeping settlement to a limited range and avoiding serviceability damage to superstructure (Eslami and Gholami, 2006).

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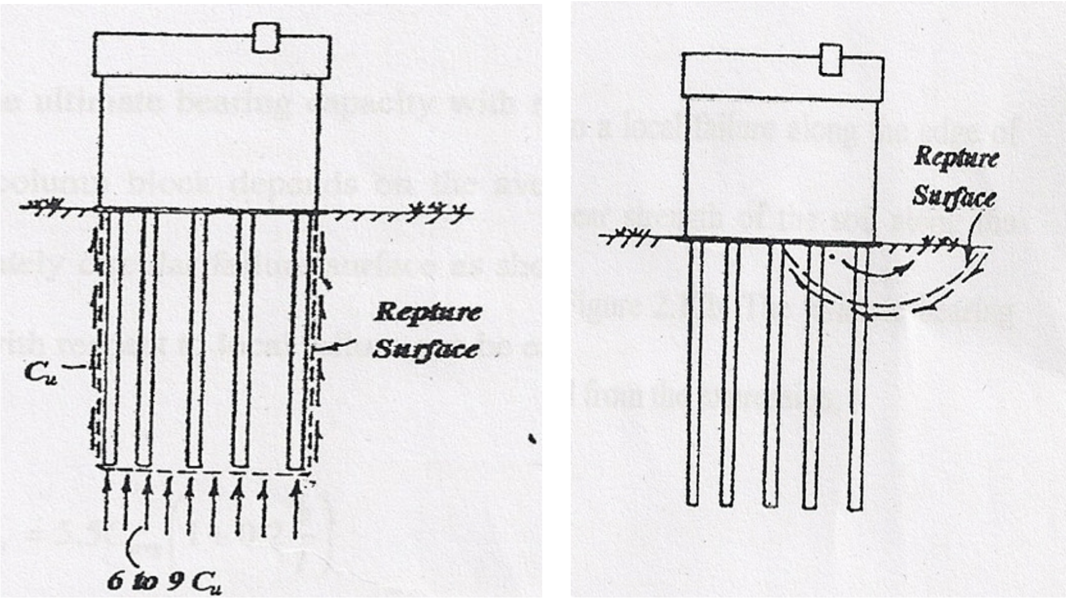

(a) **(b)**

Figure 1. Failure mode of lime -column foundations. (a) Block failure; (b) Local shear failure.

Field experiment, conducted by Islam (2009a, b) to stabilize peat soil by soil-cement column technique using cement and $CaCl_2$ as binder, was revealed that considerable improvement of bearing capacity was observed after stabilization. Hand operated cone penetrometer was used for bearing capacity observation after stipulated curing time. Nevertheless, the accuracy of the result observed from the hand operated cone penetrometer is not up to the mark when compare with the result from the static load test. In consequence of the previous test, the purpose of this study is to stabilize peat soil by group of soil-cement column and to observe the settlement of the group column for different applied loads after 28 days curing time by static load test method.

ULTIMATE BEARING CAPACITY OF GROUP COLUMN

The ultimate bearing capacity of a column group is governed either by the shear strength of the untreated soil between the columns and the shear strength of the column material (Broms, 1991). Possible shear failure of a group of columns is shown in Figure 1. Failure is either governed by the bearing capacity of block with lime columns below the structure as shown in Figure 1a, or by the local bearing capacity of block along the edge as indicated in Figure 1b when the spacing of the column is large. The bearing capacity of a group of columns arises from the skin resistance along the perimeter of the column group ($2.c_u.l_c.(B + L)$) and the base resistance of the block, which is 6 - 9 times the undrained strength of the soil c_u. Hence, the total bearing capacity of a group of columns can be written as:

$$Q_{group(ultimate)} = 2.c_u.l_c(B+L)+(6 \text{ to } 9).c_u.B.L \qquad (1)$$

where L = block length, B = block width, l_c = column height and c_u = undrained strength of surrounding soft soils. The factor 6 refers to a foundation with L > B, whereas, the factor 9 can be used for square foundations. However, in a relatively large deformation, 5 - 10% of the width of the loaded area is required to mobilise the maximum base resistance. It is therefore, proposed to neglect the base resistance in the design (Broms, 1991).

METHODOLOGY

The study was conducted in Klang, Selangor Dharul Ehsan, Malaysia, which is situated 35 kM north-west capital City Kuala Lumpur. Klang peat has high moisture content and this soil has been categorized as fibrous peat (Hashim and Islam, 2008a). Indexed properties of Klang peat are as shown in Table 1.

Pulverised Fuel Ash (PFA) cement and calcium chloride ($CaCl_2$) were used as binding agent and well graded siliceous sand was used as filler material to stabilized peat soil. Binder was used at a dosage rate of 300 kg/m^3 by weight and Table 2 shows the mixing proportion of PFA cement, $CaCl_2$ and sand.

PFA (Pulverised fuel ash) is a residue gotten from of combustion process in the boilers of coal fired power stations. It is extracted as a fine powder from the flue gasses and hence, its other common name ‘fly ash’. The chemical composition of PFA depend upon the type of coal used and can vary considerably, as pozzolanic

Table 1. Indexed properties of Klang peat (Hashim and Islam, 2008b).

Index properties	Average
Natural moisture content (%)	555
Specific gravity	1.24
Initial void ratio	9.329
Fibre content (%)	90.39
Ash content (%)	3.55
Bulk density (kg/m^3)	1037.72
pH of peat	3.51
Liquid limit (%)	208.39
Plastic index (%)	115.8
Plastic limit (%)	57.95
Permeability K(m/s)	3.5E-4

Table 2. Mixing proportion of binder.

Dosage rate	High setting PFA cement	Calcium chloride	Sand
300 kg.m^{-3}	100% of total binder	4% of total binder	25% of total in volume basis

Table 3. Properties of high setting PFA cement.

Property	Value
Physical properties	
Bulk density (γ_b), Mg/m^3	1.45
Specific gravity (G_s)	3.05
Chemical properties	
Energy dispersive X-ray (EDX):	
Analysis (EDX):	
O (%)	34.48
Br (%)	0.00
Al (%)	3.79
Si (%)	13.31
Ca (%)	41.83
Fe (%)	2.89

Table 4. Properties of sand.

Property	Value
Physical properties	
Bulk density (γ_b), Mg/m3	1.61
Specific gravity (G_s)	2.66
Chemical properties	
Energy dispersive X-ray (EDX):	
O (%)	40.86
Al (%)	8.91
Si (%)	39.71
Au (%)	10.52

reactivity. Physically, PFA is a fine (less than 75 micron) powder, which gives faster pozzolanic reactions. High setting cement is a special type of cement that is used in the construction industries such as water bound structure where quick setting of cement is necessary. This cement obtains fuel ash, which help in quick setting. MASCRETE brand cement produced by LAFARGE has been used in this study as high setting PFA cement. Table 3 shows physical properties of high setting PFA cement.

Dehydrate Calcium chloride ($CaCl_2.2H_2O$) has been used as admixture in this experiment. Minimum assay content of this substance was 74%. Maximum impurities were free alkali Iron (Fe) of 0.005%, Magnesium and alkalies (sulphate) of 0.5%. Sand plays a vital role in enhancing the bond in cementation reactions of soil mixing. It was found that grain size distribution provides a satisfactory skeleton, and the voids are filled with fine-sand, giving a compact and high load-bearing capacity. Sand used in this study was collected from Kuala Selangor, Selangor in Malaysia. Properties of sand are shown in Table 4.

Columns were constructed at site by two methods. One involved the use of mixing auger and the other was Prebored-premixed method. In mixing auger method, a 50 mm diameter and 1000 mm depth borehole was prepared by penetrating drilling piston and after drilling piston was pulled out, binder was inserted into the borehole to form binder columns and was tamped simultaneously to ensure that there was no cavity inside the binder and for the binder to get to the bottom. Three boreholes was prepared for each column in such a way that the binder was mixed uniformly. The mixing tool was rotated along the binder columns and was penetrated downward upto the desire depth. Then it was rotated in opposite direction to move the mixing tool upward.

In Prebored-premixed method, the binder was prepared and mixed in laboratory with peat, which was collected from the site and screened in a 2 mm sieve. Then the mixture was transported to the site. A bore hole of 200 mm diameter and 1000 mm depth was made by drilling auger, and the mixture was inserted into the hole. A wooden-made tempming rod of 50 mm diameter was used to temp

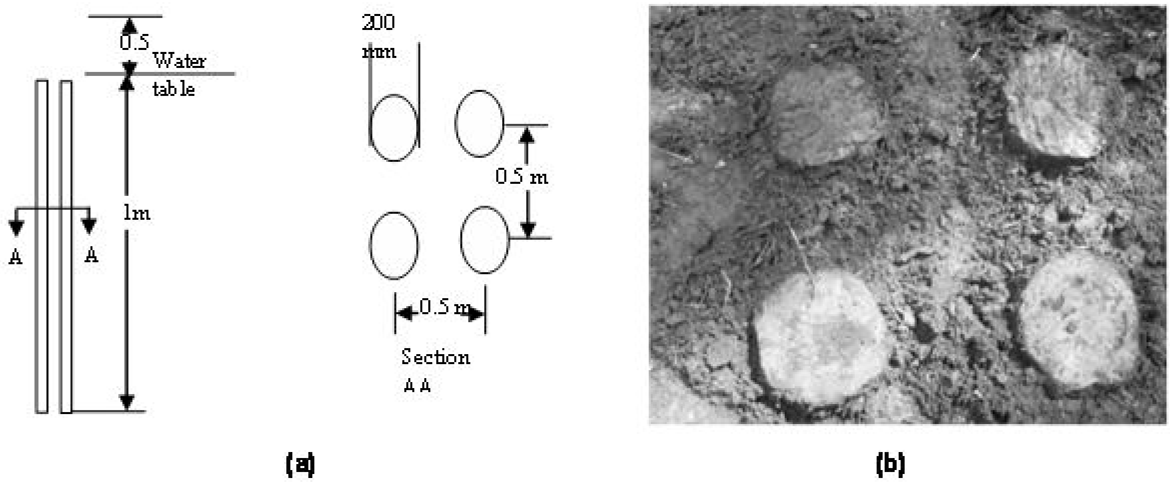

Figure 2. (a) Detail of group column (not in scale)(b) group column after 28 days.

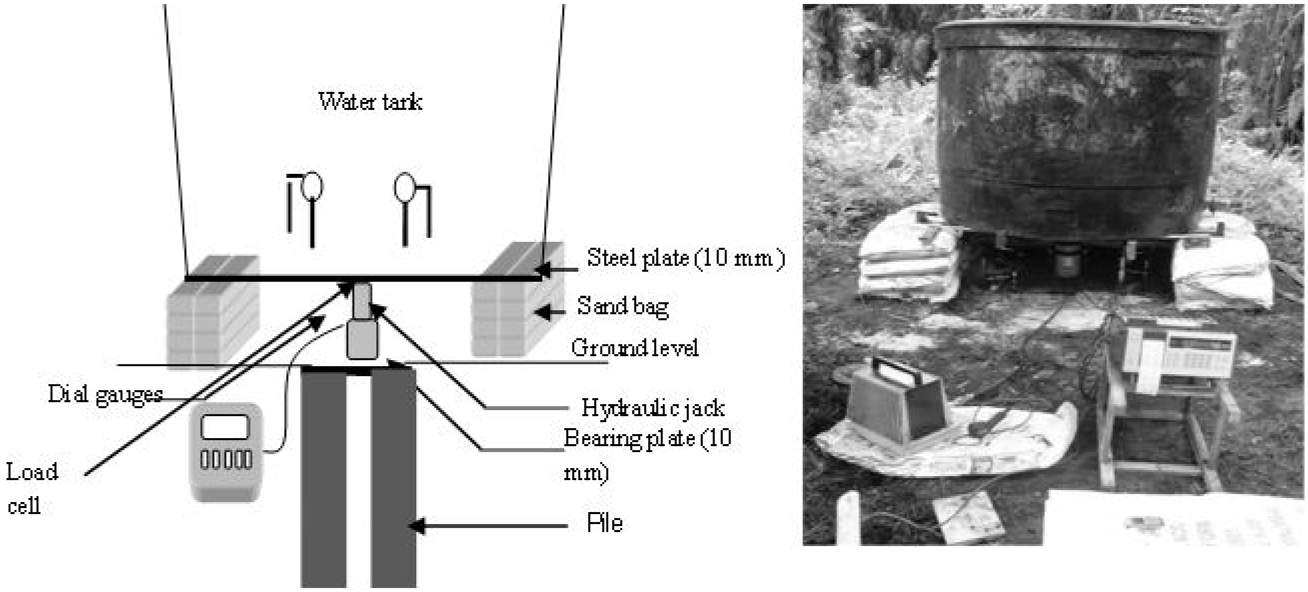

Figure 3. Static load test.

the mixture in three layers. Detail arrangement of group columns is shown in Figure 2.

Settlement of group columns for different applied load was determined by static load test. The loading equipments included 20 mm thick bearing plate, hydraulic jack, load cell, data logger, settlement gauge, load displacement transducer (LDTV) and water tank. Static load test was performed after 28 days of stabilization. Soil was excavated up to the top of the pile and bearing plate was placed on group columns. Then four numbers of LDTV was placed in four corner of bearing plate and hydraulic jack and load cell was placed at the middle of the bearing plate. Hydraulic jack and LDTVs were connected to a data logger in order to read the applied load and settlement. A water tank supported by sand bag was placed on load cell and filled by water. At first, 1 kN load was applied and readings of settlement was taken after 0.5, 1, 2, 4, 8, 12, 16, 20 and 60 min. Readings was also taken for every 1 kN applying load by same procedure and after same time. Figure 3 shows the details of static load test.

PLAXIS 8.2 software was used to establish a computer modelling to compare settlement of group columns measured by *in-situ* field test (static load test). According to the literature review, bearing capacity of a group of columns is the result of skin resistance along the perimeter of the group column, as group columns acts like a block. Thus a block of 0.7 m × 0.7 m and 1 m depth was considered to represent the group column for the computer simulation. As the PLAXIS 8.2 is two-dimensional software, the block was considered as two dimensional and other dimension was considered as unity. So, actual block size considered in the computer modelling was 0.7 × 1 m and 1 m depth (Figure 4). A bearing plate was placed over the column block and one dimensional uniformly distributed load was applied. Input parameters for computer modelling were determined by various laboratory and field experiments. Material

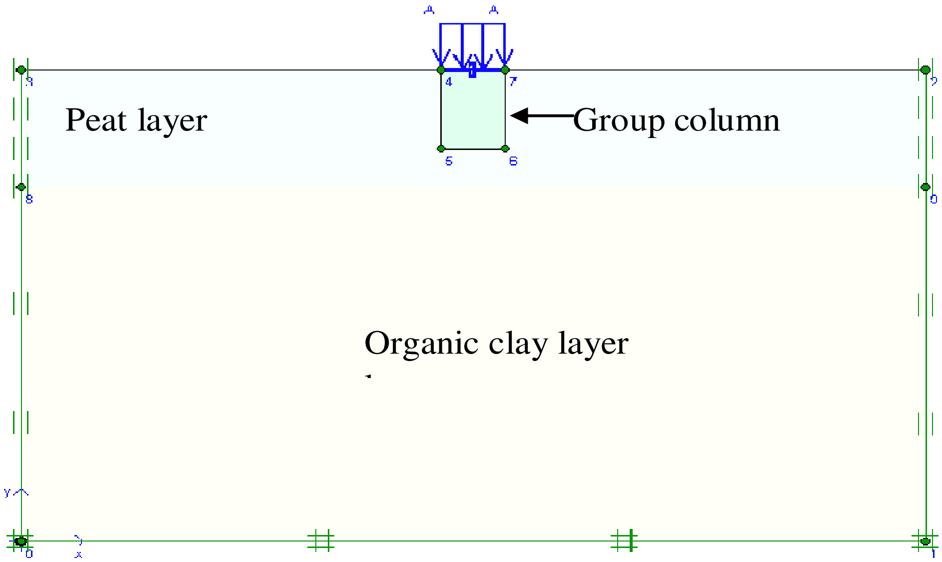

Figure 4. Formation of group column modelling for computer simulations.

Table 5. Material parameters used in computer modelling.

Soil type	**Materials parameter**							
	γ_{sat}(kN/m^3)	**γ_{unsat}(kN/m^3)**	**E(kN/m^2)**	**v**	**C$^/$(kN /m^2)**	**Φ (^{0})**	**k_x (m/min)**	**$k_{y(}$m/min)**
Untreated peat for Prebored – premixed column	10.02	8.21	770	0.35	4.7	24	2.676E-07	1.338E-07
Untreated peat for stabilized column by mixing auger	10.02	8.21	500	0.35	4.7	24	2.676E-07	1.338E-07
Stabilized column by Prebored-premixed method	23.00	20.9	6000	0.25	378	55	2.460E-10	1.230E-10
Stabilized column by mixing auger	18.9	20.34	3800	0.25	257	40	2.460E-10	1.230E-10
Organic clay	18	20	3000	0.33	130	34	6.944E-10	6.944E-10

parameters that are considered in computer modelling are given in Table 5.

RESULTS AND DISCUSSION

For the columns constructed by mixing auger, uneven settlement for applying load occurred due to the fact that four columns of the group could not be installed uniformly. However, more or less uniform settlement was recorded for the other group of columns that were installed by Prebored-premixed method. Figures 5 and 6 shows the load-settlement curves of the group columns using mixing auger and Prebored–premixed method, respectively. Due to the limitations of equipments, maximum 30 kN load could be applied for static load test. From the load-settlement curve in Figure 5, it is observed that settlement increased steadily due to the increment of applied load. Finally, 17.5 mm settlement of the group columns constructed by mixing auger is observed for 30 kN applied load. Similarly, thesame trend of load-settlement curve is viewed for the group columns installed by Prebored premixed method (Figure 6) and in this case maximum 13.8 mm settlement was found for 30 kN load.

Figure 7 show the comparison of load vs. settlement curves of computer model study and static load test for the group peat-columns that were constructed by mixing auger. From Figure7, it is obvious that both lines have a similar trend of gradual increment of settlement due to the increase of applied load. Although lower settlement value from computer modelling compare to that from static load was observed before 10 kN of applied load, the deviation steadily increases after 10 kN. Finally, 23 mm of settlement is found from computer simulations for 30 kN of applied load, which is 6 mm higher than the settlement value of static load test for same applied load.

Besides, Figure 8 shows the comparison of

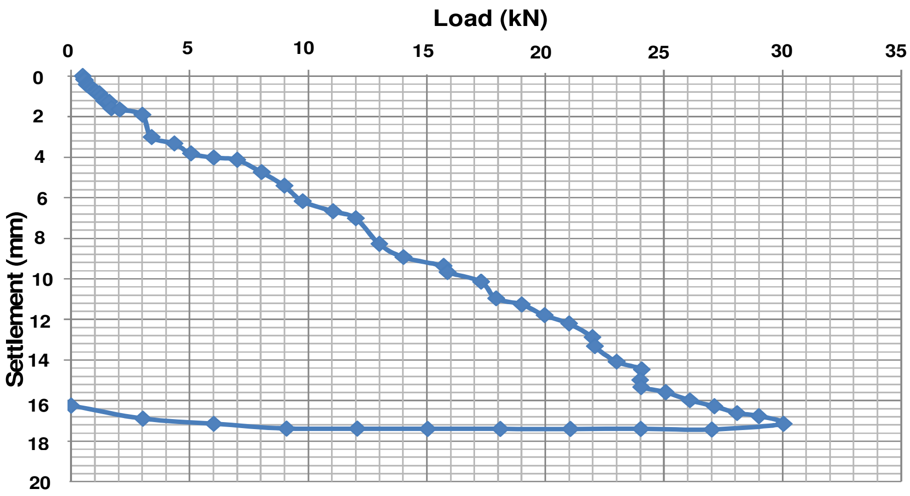

Figure 5. Load vs. settlement curve for group column formed by mixing auger.

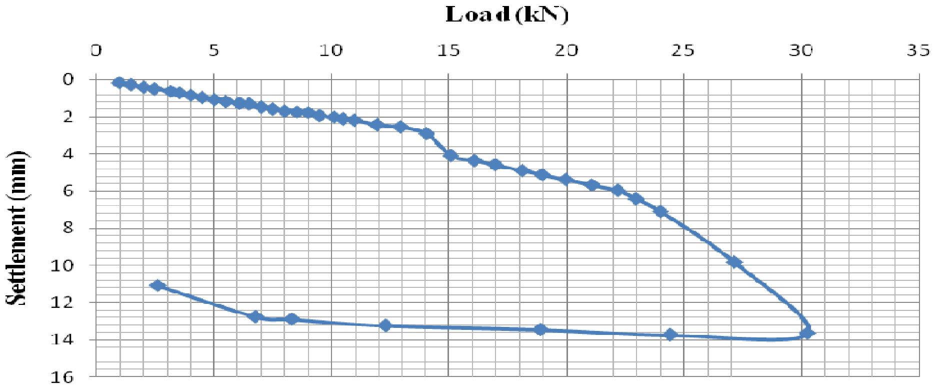

Figure 6. Load vs settlement curve for group column formed by Prebored premixed method.

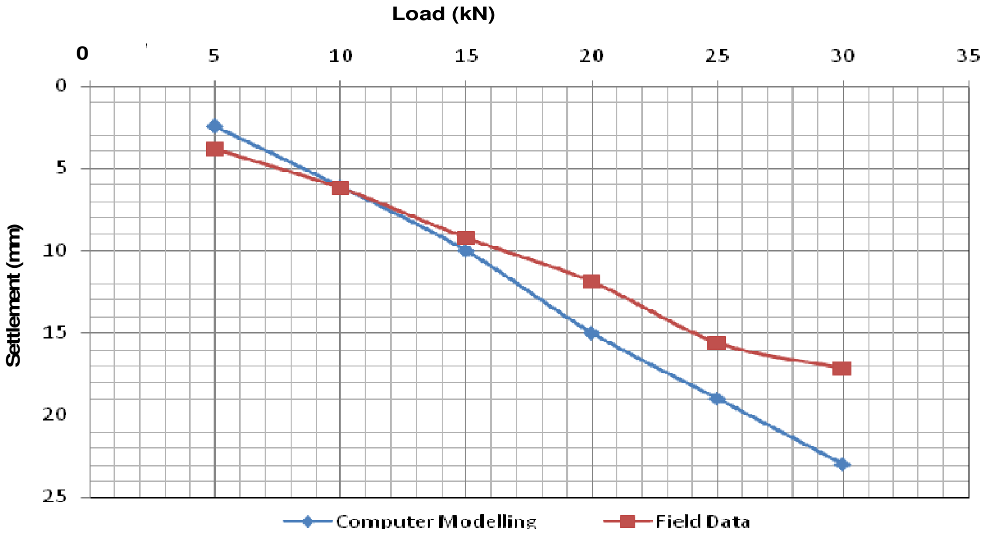

Figure 7. Comparison of Load-settlement between computers modelling and field test data (For the group columns installed by mixing auger).

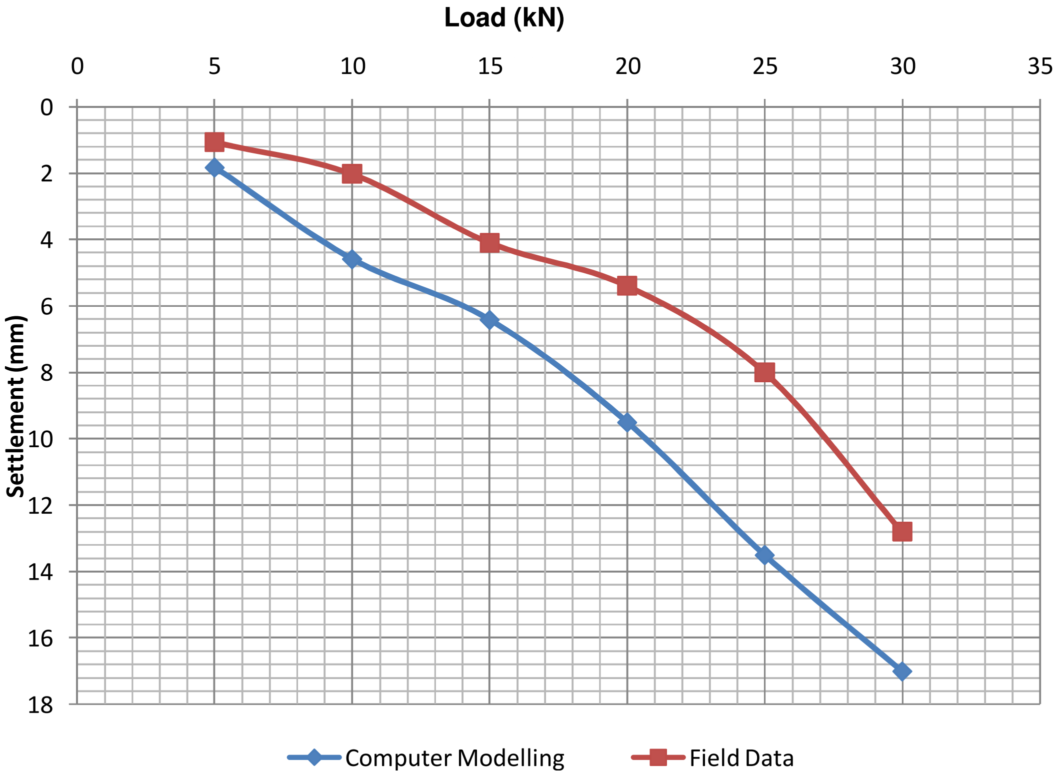

Figure 8. Comparison of Load-Settlement between computers modelling and field test data (For the group columns installed by Prebored-premixed method).

load-settlement curve for the group columns that were installed by Prebored-premixed method. Like previous case, a similar trend between the load-settlement curves for the group peat-columns that were constructed by Prebored-premixed method was also observed. In this case, settlement values of computer modelling are always higher than that of the static load test and the difference of settlement gradually increases with applied load. Eventually, 16 mm settlement for 30 kN load was observed for computer simulations, although 13 mm of settlement was recorded from field experiment for same applied load.

In both cases, is a significant deviation between measured and computer simulated results was found. This is due to the fact that to get true parameters that are require for computer modelling is quiet difficult. Thus, it could not be possible to formulate representative soils for simulations, which are similar to the actual field condition. Moreover, PLAXIS 8.2 is a two dimensional software. As a result, it was quite impossible to create a circular column and square pattern representative soils that made differences between two results. On the other hand, uniformly distributed load was considered along the vertical direction, while in horizontal direction, it was considered as unity, which did not represent the actual loading condition. This was the other reason for deviation.

Conclusion

The findings of this research will advance our knowledge on the engineering properties of tropical peat and the steps forward in the development of peat soil stabilization technique by soil-cement column using binder and chemical admixture. The following are the main conclusions drawn from the topical peat characterization and *in-situ* peat soil stabilization:

1. To enhance the bearing capacity and strength of problematic peat soils, group column gives higher value than the single column, because group column acts as a block I and failure depends upon the skin friction along the periphery of the group column and end bearing. Floating type of column has been considered in this research and the end bearing was zero.
2. Settlement value for static load test after 28 days curing period of group columns constructed by Prebored-premixed method using rapid setting PFA cement, calcium chloride and sand, was 13.6 mm. But when the mixing auger for same binder and same curing period was used, the settlement value was 17.2 mm.

3. A deviation was found when comparison was made for settlement of group columns that were found in field testing and computer modelling. For the group columns prepared by Prebored-premixed method using rapid setting PFA cement, calcium chloride and sand as binder, the settlement for 30 kN load was 4 mm higher in computer modelling than the field testing data. For the group columns constructed by mixing auger using same binder computer modelling gave 2.8 mm higher settlement than the field testing data. Computer modelling gave higher settlement value and this is due to fact that it is very difficult to determine the actual *in-situ* parameters of soil and stabilized column by laboratory experiment. Nevertheless, the values were close and this is acceptable for field model testing.

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