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Compressibility behaviour of peat reinforced with precast stabilized peat columns and FEM analysis

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Abstract. Researches have been done to discover ways to strengthen peat soil deposits. In this model study, fibrous peat that is the most compressible types of peat has been reinforced with precast peat columns stabilized with ordinary Portland cement and polypropylene fibres. Rowe cell consolidation tests as well as plate load tests (PLTs) were conducted on various types of test samples to evaluate the strength and deformation of untreated peat and peat reinforced by various types of columns. PLTs were conducted in a specially designed and fabricated circular steel test tank. The compression index (C_c) and recompression index (C_r) of fibrous peat samples reduced considerably upon use of precast columns. Also, PLT results confirmed the results obtained from Rowe cell tests. Use of polypropylene fibres added to cement further decreased (C_c) and (C_r) and increased load bearing capacity of untreated peat. Finite element method (FEM) using Plaxis 3D was carried out to evaluate the stress distributions along various types of tested samples and also, to compare the deformations obtained from FEM analysis with the actual maximum deformations found from PLTs. FEM results indicate that most of the induced stresses are taken on the upper portion of tested samples and reach their maximum values below the loading plate. Also, a close agreement was found between actual deformation values obtained from PLTs and values resulted from FEM analysis for various types of tested samples.

Keywords: precast stabilized peat columns; compression index; recompression index; Rowe cell; Plate load test; FEM

1. Introduction

Normally Peat represents the extreme form of soft soil. It is an organic soil consisting of more than 70% of organic matters. Peat deposits are found where conditions are favorable for their formation.

The word "peat" refers to a highly organic soil derived primarily from remains of plants. It has a dark brown to black colour, a spongy consistency, organic odour, high liquid limits, and very low plastic index. Among the three types of peat, namely fibric, hemic, and sapric, the first type (fibric or fibrous) is the most compressible of three types (Kalantari *et al*. 2010).

Peat soil deposits are weak; much weaker and more compressible than inorganic soils, and

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therefore do not provide suitable support for most engineering projects (Amaryan *et al*. 1973, Gautschi 1965, Kalantari and Huat 2009, Rahadian *et al*. 2001, Yamaguchi *et al*. 1985). The most usual methods among civil engineers so far to deal with peat soil deposits have been either to remove this weak soil and replace it with a more suitable soil or to pass piles through it and in to the stronger soil layers below.

On the other hand, researches have been carried out to discover ways to strengthen peat deposits. These methods include, peat stabilization using a mixture of various binders such as cement or lime, and different chemically active or inactive admixtures such as fly ash, blast furnace slag, silica fume and polypropylene fibres (Huat 2004, Kalantari 2011, Axelson *et al*. 2002, Kalantari and Huat 2008). Also, the behavior of peat has been improved by stabilization techniques where the binders are mixed with the in-situ peat to create columnar reinforcement in the ground (Alwi 2008, Hebib and Farrell 2003).

Black *et al*. (2007) used peat, cement and sand to produce cast-in-situ columns to strengthen peat deposits. Organic deposits have been mixed with inorganic soils also, such as silt and clay, producing a soil that is not as unstable as peat although less stable than inorganic deposits (Huat 2004). Different amounts of sand were mixed with peat and used as columns to reinforce peat in laboratory scale by Jorat *et al*. (2014). Forrest and MacFarlane (1969) had carried out field studies on the response of plate load test on peat and reported that the stresses applied to peat result in developed pore pressures greater than the increase in vertical stresses.

Also, in order to strengthen peat deposits, precast stabilized peat columns that were made of the in-situ peat added with cement with or without polypropylene fibres have been used. These were formed outside the ground in different mould sizes, and then placed in the pre-drilled peat samples and evaluated for their shear strength using UCS, CBR, and triaxial tests (Kalantari and Huat 2009).

In the present model study, precast stabilized peat columns with ordinary Portland cement, with and without the addition of polypropylene fibres have been investigated for their compressibility behavior when they are used in fibrous peat. To fulfill this purpose, consolidation tests using Rowe cell apparatus was used. Two important parameters, compression (C_c) index and recompression index (C_r), which are significant factors in compressibility behaviour of plain or untreated peat as well as peat reinforced with precast columns, were studied in this laboratory research. These parameters were found for undisturbed peat as well as for peat reinforced with precast columns. Also, in-order to investigate the bearing capacity of precast stabilized peat columns, plate load test has been conducted on untreated peat, as well as peat reinforced (treated) with various types of precast columns in a laboratory designed and fabricated steel test tank.

Finally, finite element analysis using Plaxis 3D was carried out to simulate the behavior of the plate load test conducted in the test tank and to evaluate the mean stresses and total deformations occurred in untreated peat as well as peat reinforced with various types of precast columns.

2. Test materials

The fibrous peat used in the study was collected from various locations in Kampung Jawa, in the western part of Malaysia and its properties are presented in Table 1. Ordinary Portland cement was used as the binding agent, and polypropylene fibres were used as chemically inactive admixture material (Fig. 1).

tkantlTable 1 Properties of peat (ASTM 1995, ASTM 2001, BS 1990)

Properties	Standard specifications	Values
Moisture content	ASTM D2216	198 – 425%
Bulk unit weight		10.23 – 10.4 kN/m^3
Classification	von Post, ASTM D5715	$H_1 – H_4$, fibrous
Organic content	ASTM D2974	80.23%
Compression index, C_c	BS EN 1997-2: 2006	3.64
Recompression index, C_r	BS EN 1997-2: 2006	0.49
Cohesion (effective), c'_u	ASTM D 4767	0.10 kPa
Friction angle (effective), φ'_u	ASTM D 4767	36.64

Fig. 1 Polypropylene fibres used in the study

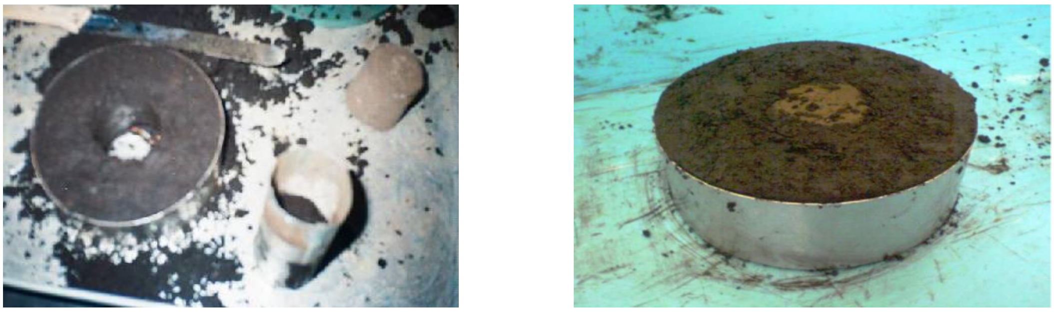
3. Experimental program

Before examining the effect of precast stabilised peat columns on the compressibility behaviour of peat, routine tests were carried out to determine the index properties, strength and compressibility behaviour of peat at its natural or untreated condition. The tests carried out include: water content, Atterberg limits, compaction, organic content, fibre content, unconfined compressive strength (UCS), and triaxial (CU).

Rowe cell consolidation tests and plate load tests were also carried out on the untreated peat as well as on peat reinforced with various types of stabilized peat columns (precast columns). For Rowe cell tests, the precast stabilized peat columns were made of peat with different amounts of cement (5, 15, 30 and 50%) as well as peat added with cement (15 and 30%) and polypropylene fibres (0.15%). And for plate load tests, the precast stabilized peat columns were made of peat with 15 and 20% cement and also peat added with 15% cement and 0.15% fibres.

3.1 Samples with precast columns

The precast columns for Rowe cell tests, made of specified amounts of cement, with or without fibres, were prepared by compacting them at their respective optimum moisture contents found from compaction tests. The columns were 50 mm in diameter and 50 mm long, and had an area ratio of the 0.11. The prepared mixture was then transferred into the mould and compacted in five layers. The moulded samples were then left in oven to be completely dried and become dried or



(a) (b)

Fig. 2 Reinforcing peat with precast stabilized peat column for consolidation test: (a) Sample with hole prepared for the column; (b) Stabilized peat column inserted in the undisturbed peat sample

stabilized columns.

For preparing the peat samples with a precast column, the mould (150 mm in diameter) was filled with undisturbed peat and a thin walled metal tube (50 mm in diameter) was pushed carefully into the peat to remove the soil from within the steel tube. The steel tube was then removed and the annular space so created was filled back with the precast peat column.

Fig. 2 depicts undisturbed peat sample before and after installation of a precast column at its centre. The prepared sample with the column was then soaked for six days to be fully saturated before placing in Rowe cell apparatus for consolidation testing.

3.2 Consolidation tests using Rowe cell

The Rowe cell consolidation apparatus was developed to overcome the disadvantages of the conventional Oedometer apparatus while performing consolidation test on non-uniform deposits, such as fibrous peat. It has several advantages over the conventional Oedometer apparatus, mainly the hydraulic loading system, the control facilities, the ability to measure pore water pressure and the capability of testing samples of a large diameter (Lee *et al*. 1983).

Peat samples used in Rowe cell apparatus were 150 mm in diameter and 50 mm high. The Rowe cell was connected to a computer using GDSLAB v 2.2.7 soft ware, and was capable of recording, time, deformation and pore pressure during the progress of the test. The load increment ratio was one (LIR = 1) for the samples and each loading and unloading process was continued for 24 hours. The samples were loaded from an initial 20 kPa to a maximum of 320 kPa. After five days of loading (20, 40, 80,160 and 320 kPa), each sample was unloaded from 320 to 40 kPa.

The compression (C_c) and recompression (C_r) indices of undisturbed peat and peat reinforced with various types of precast columns were evaluated from the obtained results of Rowe cell consolidation tests (e – log P) and are presented in Fig. 3.

3.3 Plate load test

In-order to evaluate the bearing capacity and deformation of peat reinforced by precast columns, plate load test was carried out in a specially designed and fabricated circular steel test tank having 600 mm inside diameter and 1500 mm high.

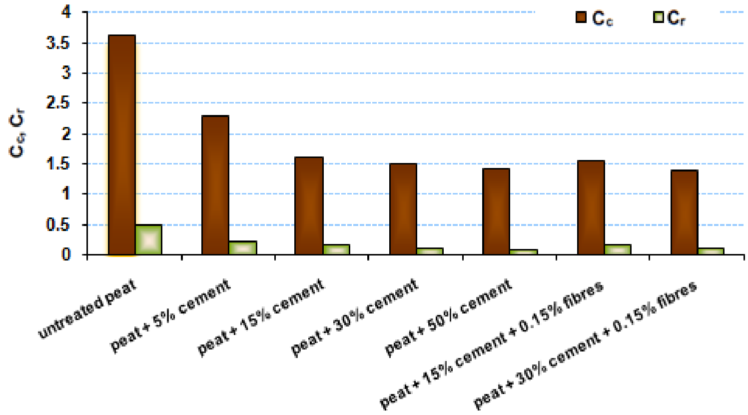


Fig. 3 Compression and recompression indices (C_c, C_r) of untreated peat and reinforced peat samples by various types of precast stabilized columns

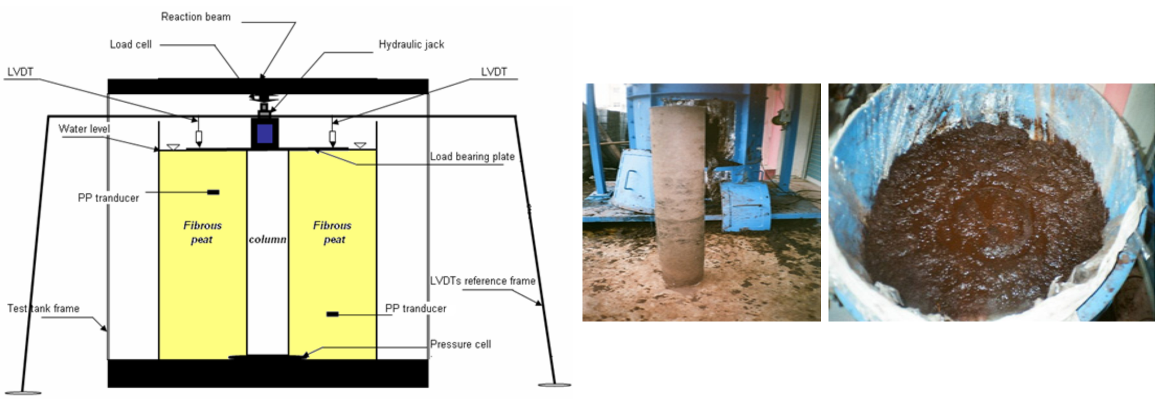


Fig. 4 Plate load test: (a) Schematic cross sectional loading diagram of peat and precast column in the test tank; (b) A precast peat column; (c) Precast peat column after being installed, and soaked in the test tank prior to be tested for plate load test

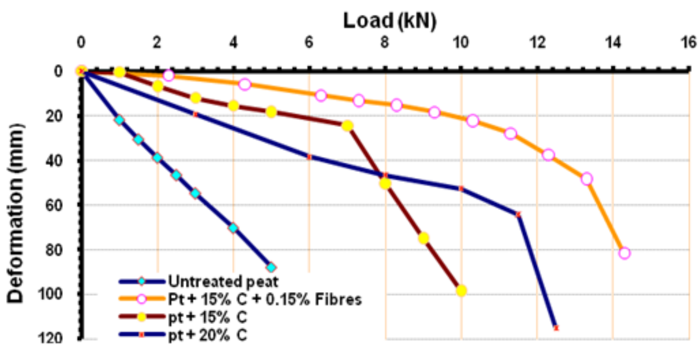


Fig. 5 Load-defomation curves for untreated peat and peat reinforced with various types of precast stabilized samples

The procedure adopted to prepare the precast columns was identical to the making of columns for Rowe cell tests. Fig. 4(a) shows a schematic diagram of a plate load test procedure conducted in the test tank. Fig. 4(b) shows a precast stabilized column prior to installation in the test tank, which is filled with remoulded fibrous peat at a bulk density equal to that in the field. Prior to carrying out the plate load test the content of the test tank (peat and precast column) was saturated for 24 hours as shown in Fig. 4(c). To prevent any leakage from the test tank, it was lined from inside with a plastic sheet. The plastic sheet was also useful in reducing the friction between peat and the test tank when the tests were being conducted.

Each tested column had a diameter of 200 mm and a length of 1000 mm with an area ratio of 0.11. A total of four sets of plate load tests were carried out with the following descriptions:

(a) untreated peat
(b) peat with precast column made of peat and 15% cement
(c) peat with precast column made of peat and 20% cement
(d) peat with precast column made of peat, 15% cement and 0.15% fibres

The load-deformation curves resulted from plate load tests are presented in Fig. 5.

4. Finite element method (FEM)

Geotechnical researchers such as Kim and Jeong 2011 and Anhtuan *et al*. 2014 have used only analytical FEM procedure to do a geotechnical simulation study, while other researchers such as Taha *et al*. 2009 and Dang *et al*. 2013 have used analytical FEM procedure in conjunction with actual in-situ or experimental methods to analyze and compare the obtained results from both methods.

In this study, a combined study of actual plate load tests as well as FEM analysis using Plaxis 3D, v1.1 have been carried out. The shear strength parameters of the untreated peat as well as reinforced peat with various types of precast peat columns were utilized to simulate the plate load test and thus to have an idea about the mean stresses in the soil and the precast columns, and also to compare the deformation values obtained from actual plate load tests, with computerized model. The main parameters that were used for each type of sample are presented in Table 2.

Table 2 Main parameters used for FEM analysis

Type of sample	Material properties					
	Failure load (kN)	c'_u (kN/m^2)	φ'_u (deg)	E (kPa)	γ_{sat} (kN/m^3)	γ_{unsat} (kN/m^3)
Untreated peat	3.2	0.1	36.6	160	10.4	10.2
Peat reinforced with 15% cement precast column	7	250	10	1300	15.4	11
Peat reinforced with 20% cement precast column	11.5	445	17.8	1500	21.4	14.8
Peat reinforced with 15% cement + 0.15% fibres precast column	13.3	475	19	1850	15	10

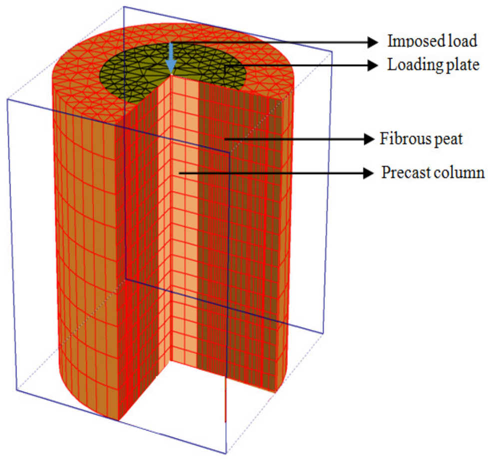
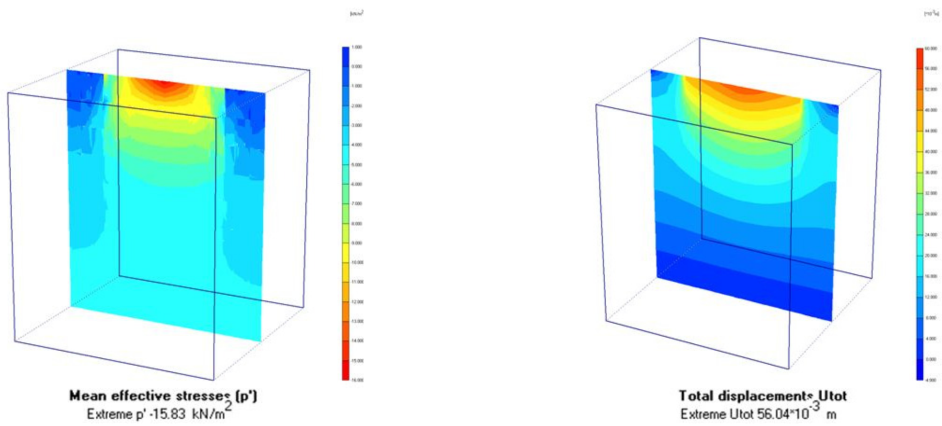


Fig. 6 General cross sectional diagram of finite element mesh grids used in the test tank for FEM analysis

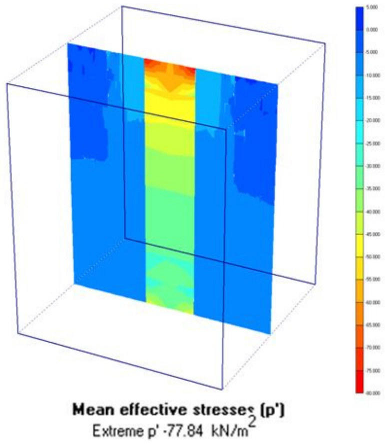
Failure load values used in Table 2 are based on the load – deformation curves presented on Fig. 5. On Fig. 5, it is observed that in the case of untreated peat, there is a punching failure and as the load intensifies, the deformations increase with a constant rate. Since, the failure point from the load – deformation curve for the untreated peat is not detectable and as the load increases the plate plunges in to the peat inside the test tank further, therefore the failure load (3.2 kN) for this particular situation is assumed to be at 10% of the plate load diameter or at 50 mm. Failure load for peat reinforced with various types of precast columns are where there is a large deformation occurring due to extra applied loads during the testing procedures, and it can be readily detected from the curve shown in Fig. 5.

Fig. 6 shows the general finite element mesh grids used for FEM analysis. Also Fig. 7 shows the simulated mean stress distributions as well as deformations of untreated peat and peat

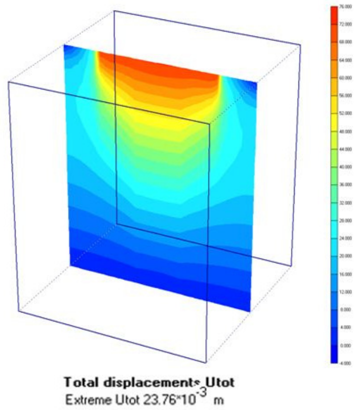


(a) (b)

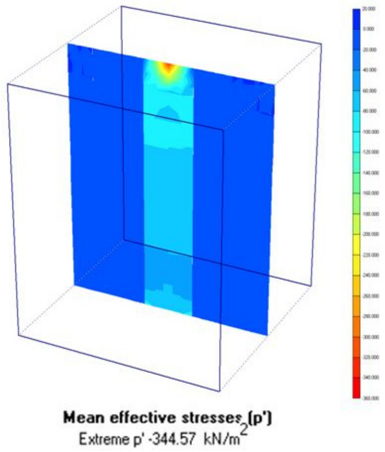
Fig. 7 Mean effective stress (left) and deformation (right) diagrams in Plaxis 3D analysis for: (a) untreated peat; (b) peat reinforced with 15% cement precast column; (c) peat reinforced with 20% cement precast column; and (d) peat reinforced with 15% cement + 0.15% fibres precast column



(c)



(d)



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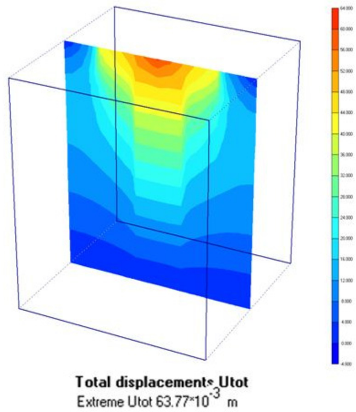

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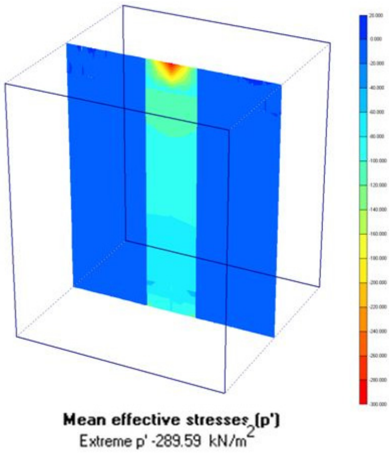

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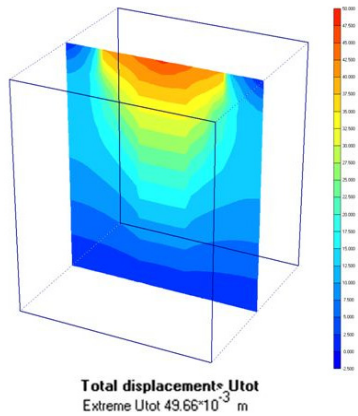

(h)

Fig. 7 Continued

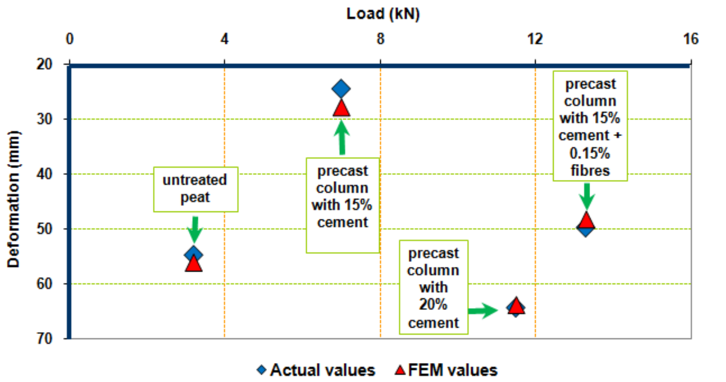

Fig. 8 Deformation values found from actual plate load tests and FEM analysis for various types of tested samples inside the test tank

reinforced with various types of precast columns inside the test tank at failure conditions.

The deformation values found from actual plate load tests at failure conditions (Fig. 5) and values obtained from FEM (Fig. 7) for four types of plate load tests are presented in Fig. 8.

5. Results and discussion

Two crucial parameters, that are important in compressibility behaviour of saturated soft soil such as peat are, compression (C_c) and recompression (C_r) indices. As and when any of these indices are reduced in saturated soft soils, for any possible reason, the settlement will be reduced by proportional amount. In this study, C_c and C_r values for peat, and peat reinforced with precast columns were evaluated using Rowe cell test and are presented in Fig. 3.

Results from Fig. 3 indicate that C_c reduced from 3.64 for untreated peat to 1.44 for peat soil stabilized with 50% cement reinforced column and to 1.5 and 1.41 with 30% cement and 30% cement plus 0.15% polypropylene fibres reinforced column respectively. Also C_c reduces from 3.64 to 2.3 when reinforced with 5% cement precast column. Similarly, C_r was 0.49 for untreated peat and it reduced to 0.22 when reinforced with 5% cement precast column and reduced to 0.11 when 50% cement is used for reinforcing column and also it reduced to 0.12 when 30% cement and 0.15% polypropylene fibres are used for reinforced column.

Results obtained from plate load tests that are presented in Fig. 5 indicate that load bearing capacity (LBC) of precast stabilized columns with 15% cement, 20% cement, and with 15% cement and 0.15% fibres were increased by 7, 11.5 and 13.3 kN respectively compared with the LBC of 3.2 kN for untreated (unreinforced) peat.

From the results presented in Fig. 7, it is observed that the mean effective stress is 15.83 kN/m^2 for untreated peat (Fig. 7(a)). It increases to 77.84 kN/m^2 when 15% cement is added to peat to form the precast column (Fig. 7(b)), and increases drastically to 344.57 kN/m^2 when with 15% cement only 0.15% fibres are added in the column (Fig. 7(c)). The obtained mean stress value of 344.57 kN/m^2 for 15% cement and 0.15% fibres is more than the mean stress value of 289.59 kN/m^2 for when 20% cement (5% more cement) is used to form the precast column (Fig. 7(d)).

Also, results from Figs. 7(a), (b), (c) and (d) indicate that induced stresses are mostly distributed at the upper portion of the untreated peat as well as reinforced peat with various types of stabilized columns. The induced stresses are at their highest intensity values at the top of the tested samples and just below the loading plate.

Also, based on the indicated results in Fig 7, most of the deformations are occurring at the induced stresses zones, and the maximum values of the deformations for all four types of loaded samples are at the top of tested samples and where the induced stresses are at their highest values.

Also, the total displacement or maximum deformation values obtained from FEM analysis (Fig. 7) for various types of tested samples (untreated peat, peat reinforced with columns having 15% cement, columns having 20% cement and also columns with 15% cement plus 0.15% fibres) were compared with their respected maximum displacement values found at failure conditions during actual plate load tests presented in Fig. 5. Obtained answers from actual plate load tests and finite element methods have been plotted in Fig. 8.

As indicated in Fig. 8, total deformation values obtained from experimental plate load tests conducted in the test tank (actual test) and their respected values for various types of tested samples found from simulated (FEM) plate load tests using Plaxis 3D are within the ranges of 96.8 to 99.8%.

6. Conclusions

In the present model study, precast stabilised peat columns with ordinary Portland cement, with and without the addition of polypropylene fibres have been investigated for their compressibility behaviour when they reinforce fibrous peat that is the most compressible type of peat soils. Based on the results obtained from two types of tests, Rowe cell consolidation as well as plate load tests conducted on untreated peat and peat reinforced with various types of precast stabilized peat columns, it is possible to conclude the following:

- When only 5% cement is used in precast columns, compression and recompression indices of reinforced peat found from Rowe cell consolidation tests are reduced by more than 63% and 45% respectively compared to indices calculated for untreated peat.
- When only 0.15% polypropylene fibres is used as chemically inactive admixture with 15% cement in precast columns, compression and recompression indices of reinforced peat found from Rowe cell consolidation tests reduce by more than 42%, and 34% compared to indices found for untreated peat respectively.
- Load bearing capacity of precast columns with 15% cement without and with fibres (0.15%) in plate load tests are increased by a factor of 2.2, and 4.16 respectively compared to LBC of untreated peat.
- Load bearing capacity of precast columns with 20% cement in plate load test are increased by a factor of 3.6 compared to untreated peat and this is 13.5% less than when columns with 15% cement (5% less cement) and 0.15% fibres are used.
- The precast stabilized peat columns made of ordinary Portland cement can be used to improve the compression behaviour and load bearing capacity of fibrous peat. These two significant civil engineering properties of fibrous peat are improved considerably further, if a small amount of polypropylene fibres are added to cement as a chemically inactive admixture in precast columns.
- Reinforcing fibrous peat that is the most compressible types of peat soils when reinforced with a stiff material such as precast stabilized peat columns causes the peat to take or carry

higher loads with less deformation. The stiffness of reinforcing columns can be increased by increasing its cement amount or inclusions of small amounts of polypropylene fibres.

- Finite element analysis can be carried out to evaluate the distribution of stress intensities and deformations and their ranges along the untreated peat and also in the treated (or reinforced) peat with different types of precast stabilized peat columns. Extreme deformation ranges occurring from actual plate load tests (experimental study) with the numerical modelling (FEM analysis) on various types of tested samples can be evaluated.
- The maximum deformation values obtained from actual plate load tests in the test tank used in this study verify the respected answers found from FEM analysis. A close agreement of over 96% between these two methods (actual and numerical) was detected between all the obtained deformation values. This closeness of obtained results is an indication of relatively correct procedure used for FEM analysis in the study.

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