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COMPRESSIBLITY OF PEAT SOIL IMPROVED WITH POLYURETHANE

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Abstract

This research investigated the compressibility of natural peat soil and peat soil improved with polyurethane foam. High natural moisture content, high compressibility, low bearing capacity and medium to low permeability is a problem and characteristic of a peat soil. This problem can be solved by reducing the compressibility of the peat soil. The objective of this study is mainly to prove whether the presence of polyurethane foam as a lightweight material on peat soil can reduce the compressibility of peat soil or otherwise. Fifteen samples of peat soil taken from Johan Setia, Klang were tested using Oedometer test with load is doubled at each increment until it reaches the maximum required load which is 10kPa, 20kPa, 40kPa, 80kPa, 160kPa, 320kPa and 640kPa. Polyurethane foam is a lightweight material, therefore reduces the overburden pressure to the underlying soil, hence future settlement can be minimized to a tolerable settlement value. Based on the data obtained from analysis of Oedometer test, the compressibility parameters including void ratio, compression index and swelling index of the peat soil alone are very high which denoted extremely poor condition of the peat soil. The compressibility parameters improved significantly with the PU foam stabilization as PU act as a void filler for peat soil. A slight increase in the compressibility parameters are recorded with higher ratio of isocyanate. However, the maximum pre-consolidation pressure recorded was with PU ratio of 1:1. Therefore, the optimum ratio for PU peat stabilization is in the ratio of 1:1.

Keywords: Peat soil, polyurethane foam, compressibility, Oedometer test, initial void ratio, compression index, swelling index

1.0 INTRODUCTION

Peat has been identified as one of the major groups of soil in Malaysia. In fact, 3.0 million hectares or 8 % of the area is covered with peat [1]. Study conducted by Islam *et al*. [2] and Andriesse [3] revealed that the bearing capacity of peat soil was very low and was apparently influenced by the water table and the presence of subsurface debris. This problem can be solved by reducing the compressibility of the peat soil. This is because compressibility is one of the important parameter to be considered to cater the superstructure from settlement. In order to determine the compressibility of peat soil, the research focused on the compressibility of peat soil and the ground treatment which can be used to reduce the compressibility of peat soil. This research was conducted to determine whether the compressibility of peat soil will either decrease or increase when polyurethane foam is injected into the peat soil. Several case histories were reported in the literature where chemical stabilisation methods were successfully used to treat peat soil. Polyurethane foam is a mixture of two material known as polyol and isocyanate (natural gas base). This research was conducted using peat soil taken from Johan Setia, Klang, Selangor, Malaysia. Most of the methods for prediction of compressibility characteristics of peat soil were developed based on the results of laboratory consolidation test. Peat is a serious problem in the construction industry due to the long-term consolidation settlements even when moderate loads are applied. Thus, the peat is considered to be unsuitable to support the foundation in natural conditions. Excessive settlement lead to the instability of structural building founded on the peat soil. The objectives of this study are to enhance the compressibility of peat soil improved with polyurethane foam as one of the solution for ground improvement. The performance of polyurethane with

ratio of polyol to isocyanete 1:1 and 1:5 are evaluated in this study as peat soil improvement method.

2.0 METHODOLOGY

This research was undertaken to investigate the compressibility characteristics of peat soil and improved peat soil. The sample of peat soil was obtained at Johan Setia, Klang, Selangor, Malaysia as shown in a map in Figure 1. The undisturbed samples were properly cared to preserved the moisture content within the sampling tube for consolidation test while the disturbed sample is taken for physical properties test as shown in Figure 2. The ratio of polyol to isocyanate to form the polyurethane used in this study is in the ratio of 1:1 and 1:1.5. A one-dimensional consolidation test using the Oedometer apparatus is performed to determine the engineering properties of the soil by measuring the rate of consolidation for that particular soil sample. Oedometer tests are performed by applying different loads to a soil sample and measuring the deformation response. The results from these tests are used to predict how a soil in the field will deform in response to a change in effective stress. This research is undertaken to observe the effectiveness of polyurethane foam as a new material for ground improvement and to test the extent to which the strength and compressibility of the polyurethane foam can improve the peat.

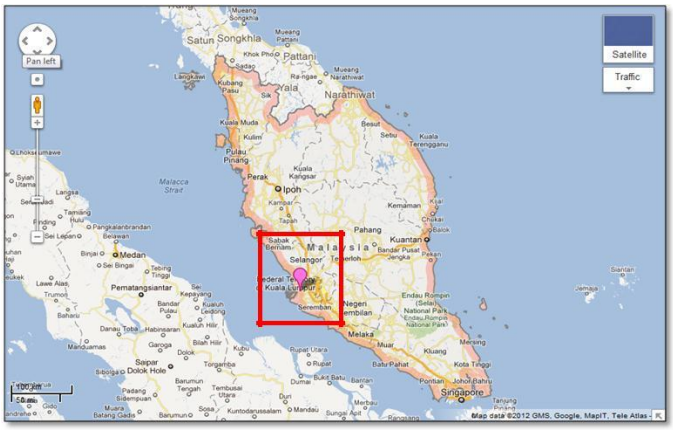

Figure 1 Map of Klang, Malaysia [4]

Figure 2 Peat soil sample; (a) undisturbed sample of peat soil taken at site, (b) The disturbed sample of peat soil

2.1 Physical and Consolidation Test

Physical testing on geotechnical properties of the peat soil has been carried out according to BS 1377, 1990 [5,6,7] to determine the moisture content, particle density, organic content, maximum dry density and compaction characteristics of the soil. The compressibility of the peat soil was determined by carrying out consolidation test using Oedometer apparatus as shown in Figure 3. Three peat soil samples were prepared having different ratio of polyol:isocyanate to investigate the effect of polyurethane on consolidation parameters of the peat soil. An undisturbed sample is used for Oedometer consolidation test with reference to BS 1377 Part 5 1990 [8]. A soil specimen in the form of a disc with 50 mm diameter and 20 mm thick was cut from an undisturbed sample.

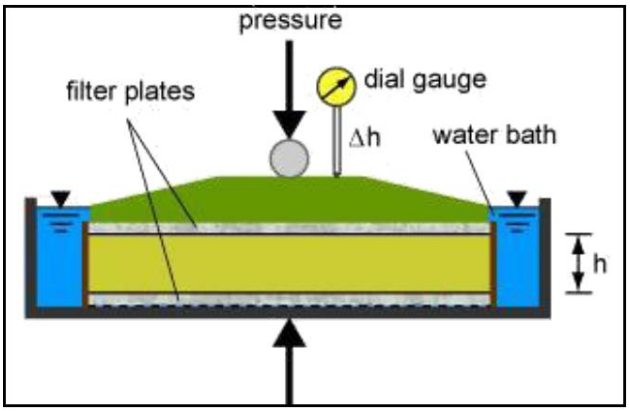

Figure 3 The Oedometer cell [9]

2.2 Preparation of Polyurethane Foam (PU)

Polyurethane is produced through a process of mixing the polyol and isocyanate with a specified ratio. Each of the ratios will produce different characteristics of polyurethane foam. Therefore, the research was to determine the optimum ratio of polyol and isocyanate to achieve durable and stiffer condition to support the soft soil. To prepare the sample, the polyol and isocyanate was injected simultaneously with a specified dose within a specified pressure into a tube of 300 mm height and 50 mm diameter. Then, the polyol and isocyanate were allowed to react for about 8 – 15 minutes and it will eventually form stiffer foam as shown in Figure 4.

Figure 4 Combination of polyol and isocyanate to form polyurethane foam

2.3 Preparation of Peat Soil Improved with Polyurethane (PU) Foam

Sample of peat improved with polyurethane foam is prepared by compacting the soil with its optimum moisture content and the polyurethane (PU) mix was injected at the center of the compacted soil using pressure devices provided by the contractor. The sample of peat soil improved with PU foam as shown in Figure 5 and the tube to place the PU at the center of the peat soil is as shown in Figure 6.

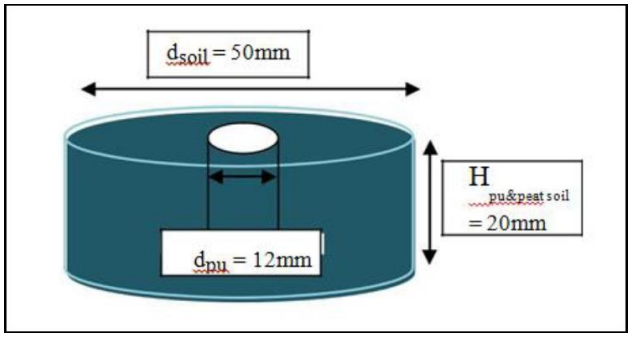

Figure 5 Tube preparation illustration of peat soil sample improved with PU

Figure 6 Tube preparation

3.0 RESULTS AND DISCUSSIONS

3.1 Physical Properties of Peat Soil

The results from physical properties test for this research are summarized in Table 1. Comparison of the properties test result has been made with other researchers [1, 10] and show that the results obtained in this study is in a good agreement with them. Extremely high moisture content about 345% and organic content of 92% with very low dry density were recorded for the peat soil in this study indicated that the soil is very problematic soil and unsuitable to be used as a soil foundation for structure. In natural state, peat consists of water and decomposed plant fragment with virtual no measurable strength. Peat is often referred as problematic soil due to its low shear strength, high compressibility high water content and organic content often more than 75% [10].

Table 1 Physical properties test result

Properies test	This study	Huat, 2004[1]
Moisture Content (%)	345	200-700
Particle Density, ρ_s (Mg/m^3)	1.23	1.22-1.7
Organic Content (%)	92.12	65-97
Maximum Dry Density (Mg/m^3)	0.66	
Optimum Moisture Content (%)	43.50	

3.2 Compressibility of Peat Soil

Table 2 summarizes the compressibility parameters of the peat soil. From this research, the value of void ratio is large due to the presence of high water content in the peat soil. Therefore the compressibility index is high. Figures 7 to 9 show the plot of void ratio against effective stress in log graph for 3 different peat soil samples respectively whereas Figure 10 shows the combination of the 3 different peat soil samples. All the peat samples show the same trend for determination of compressibility parameters. The steep slope indicated high compression index of the peat. The initial void ratio and compression index are very high due to high moisture content in the peat soil.

Table 2 Properties of peat soil in this study

Sample	Initial void ratio, e_o	Compression index, Cc	Swelling index, Cs	Preconsolidated pressure, Pc' (kPa)
Peat 1	10.9383	1.1713	0.099	28
Peat 2	10.5757	1.3269	0.0867	18
Peat 3	10.1904	1.1863	0.0712	16

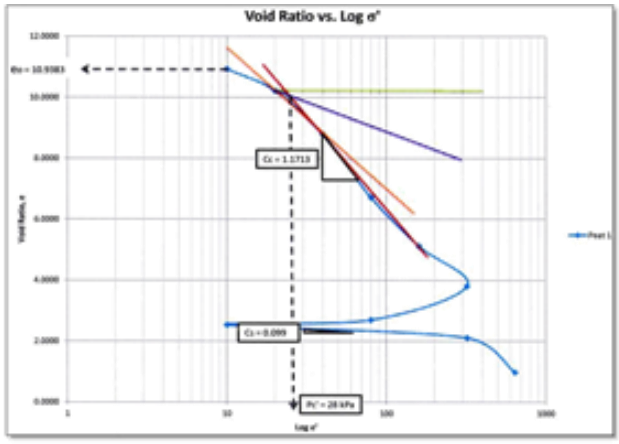

Figure 7 Void ratio against log σ′ for peat soil sample 1

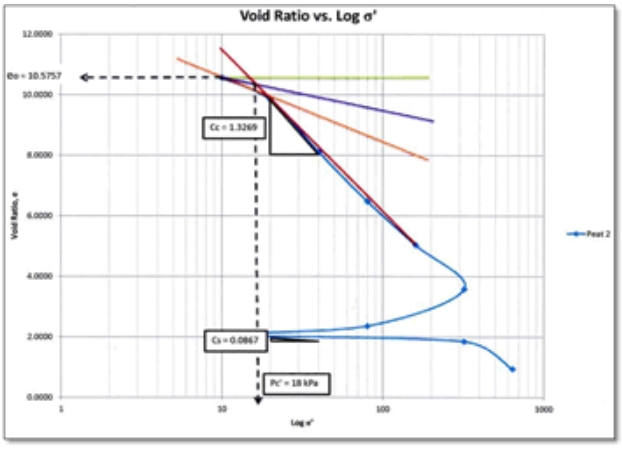

Figure 8 Void ratio against log σ′ for peat soil sample 2

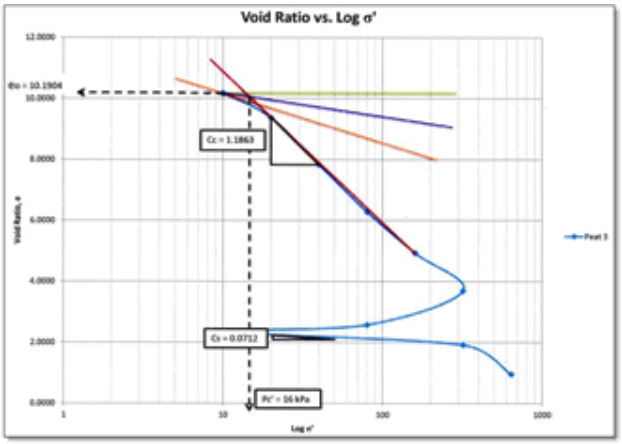

Figure 9 Void ratio against log σ′ for peat soil sample 3

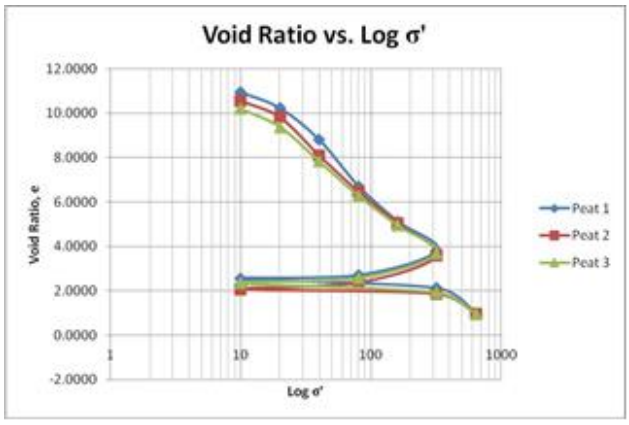

Figure 10 Void ratio against log σ′ for natural peat soil samples 1, 2 and 3

3.3 Compressibility of PU Foam Sample with Ratio of polyol to isocyanate 1:1

Consolidation test was conducted on the PU foam samples with ratio of polyol to isocyanate 1:1 to determine its compressibility parameters. The results of the consolidation test are tabulated in Table 3. PU foam has lower value of void ratio, therefore the compression index is lower. It shows that PU is able to improve the properties of highly compressible soil as it has a good compressibility property. The plot of void ratio against log effective stress for different samples of PU are shown in Figure 11 to 13 respectively.

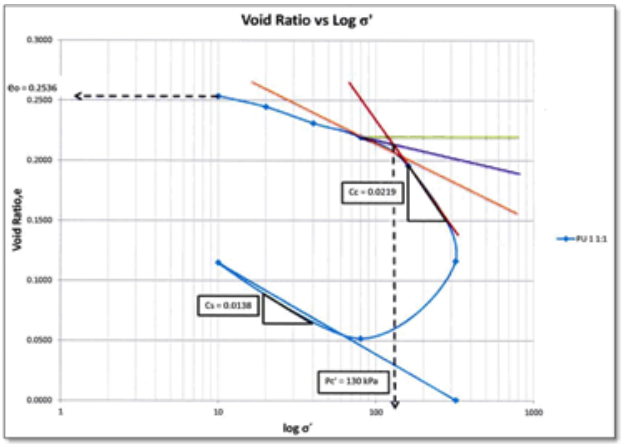

Figure 11 Void ratio against log σ′ for PU sample 1

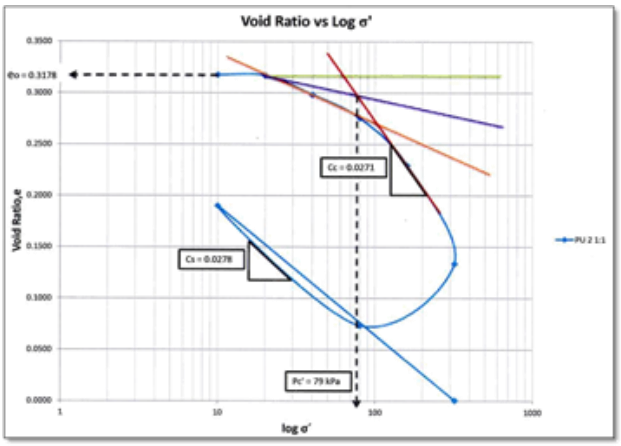

Figure 12 Void ratio against log σ′ for PU sample 2

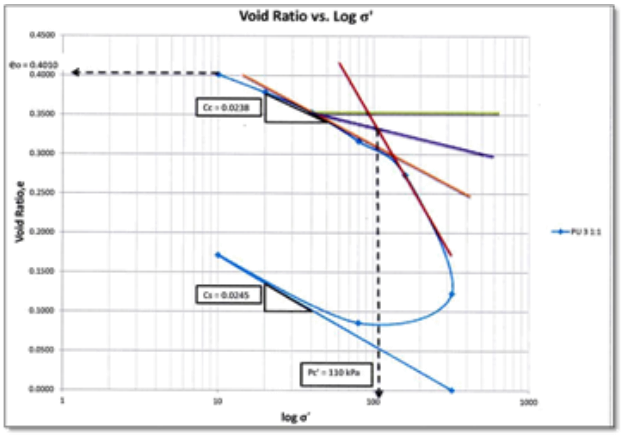

Figure 13 Void ratio against log σ′ for PU sample 3

Table 3 Compressibility parameters for PU foam with ratio of 1:1

Sample	Initial void ratio	Compression index, Cr	Swelling index, Cs	Preconsolidation pressure (kPa)
PU 1 1:1	0.2536	0.0219	0.0138	130
PU 2 1:1	0.3178	0.0271	0.0278	79
PU 3 1:1	0.4010	0.0238	0.0245	110

3.4 Compressibility of Improved Peat Soil Sample with PU Foam Ratio of polyol to isocyanate 1:1

Compressibility parameters for peat improved with PU foam was determined and the results are tabulated in Table 4. The compressibility of the peat has improved significantly with the injection of PU foam whereby the injection of PU has filled the void and partly replaced peat soil hence reduced the the void ratio and the compressibility index significantly. The pre-consolidation pressure is higher compared to the existing peat soil. The same trend occurred for the three different improved peat soil samples and combinations of the samples as shown in Figures 14 to 17. The plot of void ratio against log σ showed the shallow slope gradient of Cc indicating low value of Cc.

Table 4 Compressibility parameters for peat improved with PU foam with ratio of 1:1

Sample	Initial void ratio	Compression index, C_c	Swelling index, C_s	Preconsolidation pressure (kPa)
Peat + PU 1	0.1491	0.0153	0.0119	60
Peat + PU 2	0.1462	0.0154	0.0099	42
Peat + PU 3	0.1539	0.0178	0.0096	60

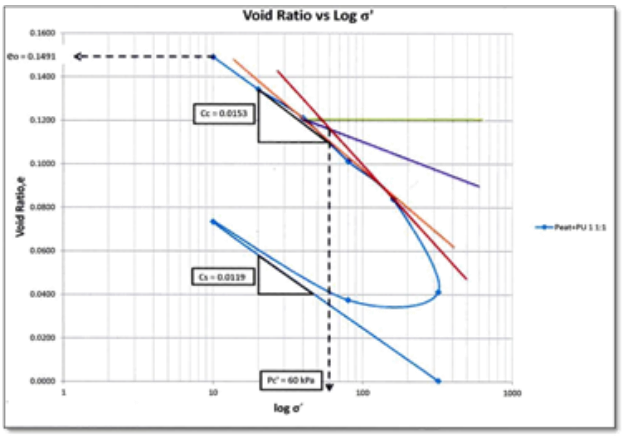

Figure 14 Void ratio against log σ′ for improved peat soil sample 1

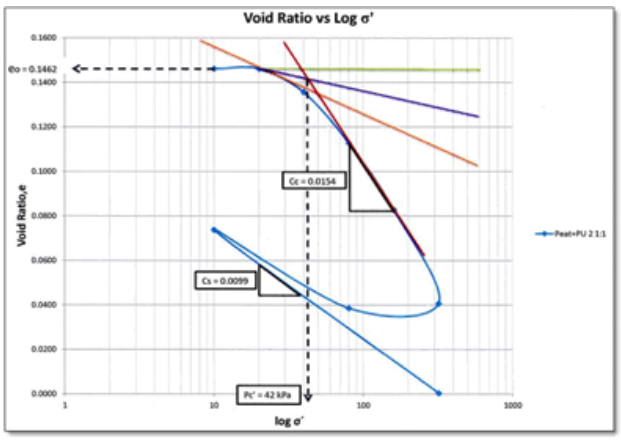

Figure 15 Void ratio against log σ′ for improved peat soil sample 2

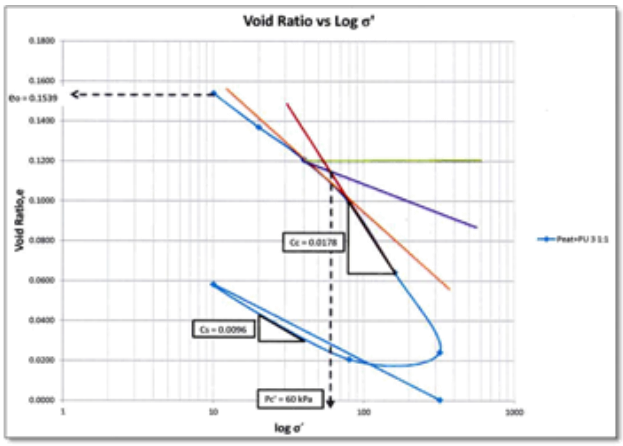

Figure 16 Void Ratio against log σ′ for improved sample 3

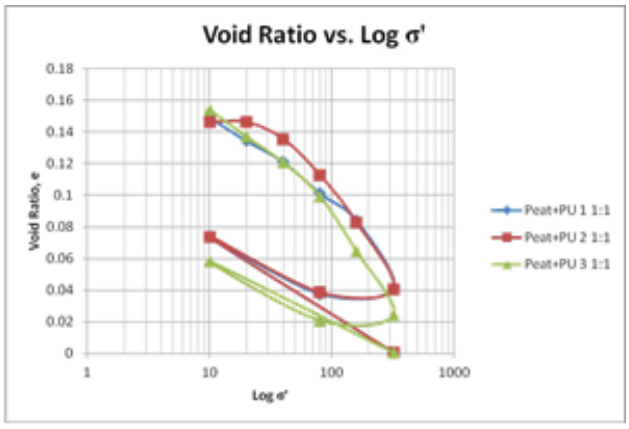

Figure 17 Improved Peat Soil Samples with ratio of polyol to isocyanate 1:1 for samples 1, 2, 3

Table 5 Summary of sample comparisons for peat, PU foam and improved peat soil with PU foam with ratio of 1:1 (polyol to isocyanate)

Sample	Initial void ratio, e_o	Compression Index, Cc	Swelling Index, Cs	Preconsolidation pressure, Pc
Average Peat	10.568	1.2282	0.0856	21
Average PU 1:1	0.3241	0.0243	0.022	106
Average Peat +PU	0.1497	0.0162	0.0105	54

Based on Table 5, the results show the injection of PU with 1:1 ratio of polyol to isocyanate has successfully improved compressibility parameters of peat soil. Initially, the peat soil has poor compressibility characteristics including high natural moisture content, high compressibility, low bearing capacity, and low permeability. The compressibility characteristics of peat have been improved significantly with the injection of PU foam at the center of the peat soil sample as shown in Table 5.

3.5 Comparisons of Compressibility of Improved Peat Soil with Different Ratio of Polyol to Isocyanate

The improved peat soil with PU ratio 1:1 (polyol:isocyanate) is compared with the improved peat soil with PU ratio of 1:5 (polyol:isocyanate). Figure 18 shows the plot of void ratio againts log σ for peat soil improved with PU in different ratio of 1:1 and 1:5 (polyol to isocyanate). Both ratios exhibited the same trend of plot.

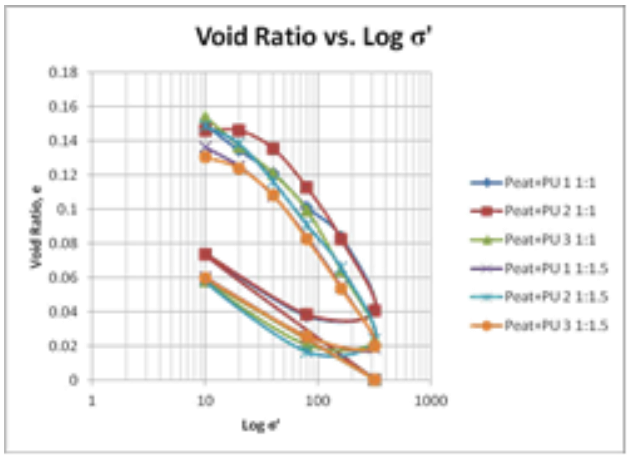

Figure 18 Comparisons of the improved sample with ratio of polyol to isocyanate 1:1 & 1:1.5 to form PU

Table 6 Summary of improved peat soil at different ratio of polyol to isocyanate 1:1 and 1:1.5 to form PU

Sample	Initial void ratio, e_o	Compression Index Cc	Swelling Index Cs	Pre-consolidation pressure, Pc
Average peat	10.568	1.2282	0.0856	21
Average Peat+PU 1:1	0.1497	0.0162	0.0105	54
Average Peat+PU 1:1.5	0.1385	0.0155	0.0104	32

The results of improved peat soil with different ratio of polyol to isocyanate to form PU foam as shown in Table 6 shows the average eo and Cc of the peat soil alone is very high with value of 10.6 and 1.228 respectively. With the PU stabilization, the eo and Cc values reduced significantly. There is a slight reduction in the average eo and Cc with the increase of isocyanate ratio. With the ratio of polyol to isocyanate 1:1, the average eo and Cc is 0.15 and 0.016 respectively whilst they reduced with the ratio of polyol to isocyanate 1:1.5. It shows that the increase in isocyanate ratio help to produce stiffer polyurethane foam which improves the void filling characteristics of the PU foam. However, the ratio of polyol to isocyanate 1:1 produces the optimum result as the maximum pre-consolidation pressure is achieved with this ratio and only slight difference in other compressibility parameters between both ratios. With higher pre-consolidation pressure, Pc, the changes in void ratio of the improved soil is small when subjected to the load which is less than the Pc. Therefore, the amount of settlement is reduced accordingly.

4.0 CONCLUSION

This research was conducted in order to investigate the compressibility of peat soil before and after improving with polyurethane foam. The following conclusions are drawn from this research:

-Polyurethane foam is a lightweight material, therefore reduces the overburden pressure to the underlying soil, hence future settlement can be minimized to a tolerable settlement value.

-Based on the data obtained from the analysis of Oedometer test, the compressibility parameters including void ratio, compression index and swelling index of the peat soil alone show very high compressibili compressibility which denoted extremely poor condition of the peat soil.

-The compressibility parameters improved significantly with the PU foam improvement as PU act as a void filler of peat soil. A slight increase in the compressibility parameters are recorded with higher ratio of isocyanate. However, the maximum pre-consolidation pressure recorded was with PU ratio of 1:1. Therefore, the optimum ratio for PU peat improvement is in the ratio of 1:1.

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