Compressibility Behaviour of Sapric Peat in Double Drainage Constant Rate of Strain (CRS) Test

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ABSTRACT: Peat is highly compressible, and it creeps significantly after primary consolidation. Hence, the knowledge of peat settlement characteristics is crucial for sustainable construction on peat. This paper presents the compressibility behaviour of the reconstituted tropical sapric peat specimens obtained via Constant Rate of Strain (CRS) tests by controlling back pressure equal to zero. This technique is found to be helpful to expedite the test. The specimens are compressed one-dimensionally under five different strain rates, from 0.5 %/ hour to 20 %/ hour. Three sets of conventional oedometer tests are also conducted for comparison and verification purposes. The primary compression index values obtained from the specimens vary from 3.021 to 4.146 and are found to be at the lower range for peat in the literature. It is found that the effect of strain rates in the observed range of excess pore water pressure ratio on the compressibility properties of the peat is insignificant.

KEYWORDS: Consolidation, Constant rate of strain, Strain rate, Tropical sapric peat.

1. INTRODUCTION

Peat is known for its low shear strength, high compressibility and high water retention capacity characteristics. It cannot sustain load without being deformed largely and creep significantly with time (Gofar & Sutejo, 2007; Hashim et al., 2008; Hendry et al., 2012). Despite these geotechnical challenges, infrastructure development is sometimes located in peatland. For example, the Pan Borneo Highway Project connecting the coastal areas in East Malaysia will coincide with the peat areas. Post-construction settlement problems in peat often affect the serviceability of structures and increase the overall maintenance cost of projects (Long & Boylan, 2013). Some cases of excessive peat subsidence have also been reported in Malaysia and resulting in many housing residential being abandoned. Maintenance and rehabilitation costs necessitate engineers to pay more attention to proper characterisation in order to get accurate properties and to better understand the compressibility behaviour of peat thoroughly. However, tests on compressibility behaviour are always time consuming.

Sapric peat is a general term for highly humified peat with low fiber and very little to none visible plant structure. Unlike peat found in temperate regions, peat found in tropical regions is often decomposed due to the hot and humid climate, which expedite peat decomposition. Such decomposed peat has a different fabric than fibrous peat, where fibrous has significant fiber entanglement and cellular connections (Mesri & Ajlouni, 2007). The higher the decomposition, the higher the unit weight is (Huat et al., 2014).

The estimation of peat compressibility and settlement is complex due to the high amount of organic content and changeable decomposition state. There is still a lack of research in sapric peat compared to fibrous peat with few exceptions (e.g. Lea & Brawner, 1963; Dhowian & Edil, 1980). The void ratio of peat decreases with the increase in decomposition (Landva & La Rochelle, 1983; Mesri & Ajlouni, 2007; O'Kelly & Pichan, 2013). Hence, fibrous peat generally compresses more easily than decomposed ones. The initial permeability of fibrous peat could be up to 10,000 times higher than the initial permeability of soft clay and silt, which is approximately 10^{-9} mm/s (Mesri & Ajlouni, 2007). However, the high initial permeability of peat significantly reduces when loaded, due to the closure of pores within the peat particles. The coefficient of consolidation, c_v decreases significantly owing to the decrease in permeability as the peat is loaded at higher stresses (Lea & Brawner, 1963; Mesri et al., 1997; Santagata et al., 2008).

Primary consolidation time of fibrous peat is relatively short compared to clay (Mesri et al., 1997). This is due to the high initial permeability and easy compression of the particles that make up the deposits (Mesri et al., 1997; Mesri & Ajlouni, 2007). Peat compressibility can be assessed using the primary consolidation compression index, C_c which is the slope of normal consolidation line in the plot of void ratio, e versus log of vertical stress, σ'_v ($C_c = \Delta e / \Delta \log \sigma'_v$). Note that C_c is unit-less. Peat has high C_c values, typically 2 to 15 times higher than clay, where the C_c of clay is in the range of 0.2 to 0.8 (Huat, 2004; Kazemian et al., 2011). The findings of Wong et al (2009) during earth-filling with peat materials on several sites also supported previous theories on the fast primary consolidation/compression of peat. The peat compressibility is classified into four classes, depending on the normalised primary compression index, $C_N = C_c/(1 + e_o)$. C_N for low compressible peat ranges from 0 to 0.05, slightly compressible peat ranges from 0.05 to 0.10 and moderately compressible peat ranges from 0.10 to 0.20, while highly compressible peat has C_N from 0.20 and above (O'Loughlin & Lehane, 2003).

The compressibility behaviour of soils is commonly measured using conventional oedometer test (ASTM D2435). However, such test is time-consuming as it requires load increment every 24 hours. In addition, the excess pore water pressure generation and dissipation during loading cannot be measured from the oedometer test. The above limitations have made Constant Rate of Strain (CRS) test a better option than the conventional oedometer test. Tests conducted with CRS apparatus is significantly faster and more data can be collected with a continuous loading system with less effort than that of the oedometer. More comprehensive stress versus strain curve can be obtained from a CRS test than the oedometer test (Sällfors, 1975). However, a suitable strain rate must be used during the CRS tests to minimise excess pore water pressure and ensure that the void ratio is fairly uniformly distributed within the specimen. The excess pore water pressure increases with strain rate and creep might occur if the strain rate is too low. Therefore, it is important to select a suitable strain rate for the CRS test. Wissa et al. (1971) found that the use of unsuitable strain rate would affect the CRS result. Ideally, the suitable strain rate would be fast enough to prevent creep and ensuring minimum excess pore water pressure development during loading. The ASTM D4186M standard recommends that the strain rate is estimated from the excess pore water pressure ratio, i.e. the ratio of pore water pressure to the vertical effective stress. The ASTM D4186M further recommends that the excess pore water pressure ratio measured at the bottom of the specimen should be in between 3 % to 15 %. The Swedish standard specifies 0.68 %/ hour shearing rate for typical CRS test on clay. Other published work recommends different strain rates with some ranging up to 50 % of excess pore water pressure ratio (Holm, 2016). The major limitation of the recommendations from previous research is that the strain rate is soil specific.

The pictorial description of consolidation and drainage mechanism used for this study is depicted in Figure 1. For all tests in this study, zero back pressure is imposed by using a pressure controller at the bottom of the sample to observe the excess pore water pressure behaviour at different strain rates. Imposing zero back pressure (double drainage) has found to be expediting the test and minimise the chance of soil creep. Note that the ASTM D4186M stated that the choosing strain rate should bring about ≤ 15 % excess pore water pressure ratio.

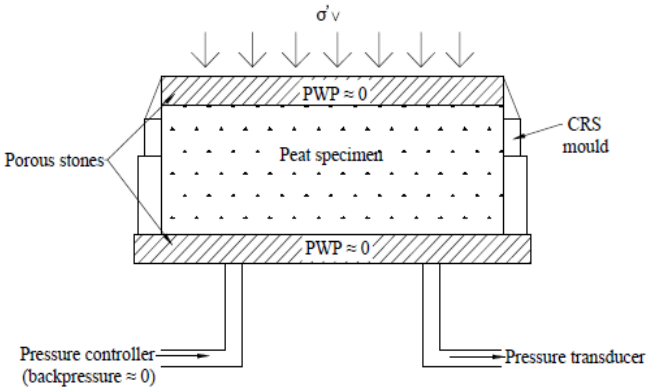

Figure 1 Consolidation mechanism in CRS

This paper presents a technical investigation of the compressibility behaviour of reconstituted sapric peat at different strain rate using CRS system by imposing zero back pressure. Reconstituted samples are used to ensure the identicalness of the tests specimens. Three sets of oedometer tests are also conducted on the same sample for comparison purposes. The strain rate effects on the compressibility characteristics of the peat are investigated.

2. PEAT SAMPLE

Peat samples used for this study are obtained from Kota Samarahan district, West Sarawak, East Malaysia (01° 25’ 37.2” N, 110° 27’ 32.3” E). The reconstituted samples are collected by scooping the peat into plastic buckets. The upper peat layer about 30 cm depth is initially removed to avoid unwanted inclusions such as dry leaves, stones and grass. The groundwater table is observed at about 0.5 m from the ground surface, and the peat water appears to be dark brown. The peat samples are scooped at a depth of 0.5 m to 1.0 m below the groundwater table. The decomposition level of peat can be assessed by analysing using hand squeezing method according to Von Post scale ranging from H1 to H10, i.e. the least to the most decomposed peat, respectively (Von Post & Granlund, 1926). Von Post humification testing is carried out in-situ and during the test, fairly uniform paste is extruded between the fingers, and few unrecognizable plant structure is left on hand after squeezing of the peat (Figure 2). Hence, the peat sample used for the present experiment is classified as H9. The plastic buckets containing the samples are covered and sealed to keep the samples in an airtight condition to avoid loss of moisture (ASTM D2944). Basic laboratory tests are conducted which include moisture content, organic content, specific gravity, fiber content and liquid limit test.

The moisture content test conducted in accordance with ASTM D2974, by drying the peat specimens in 80 °C oven for 24 hours. The oven-dried samples are further used to determine the organic content by placing them in a muffle furnace with a temperature of 450 °C for 6 hours. The specific gravity test is performed using Method B of ASTM D854 where kerosene is used as a solvent instead of water. The fiber content of the peat is determined from the ratio of the dry mass of fibers retained on No. 1 ASTM sieve (150 µm opening) to the total mass of the oven-dried sample as stated in ASTM D1997. The liquid limit is determined from the fall cone penetrometer test in accordance with BS 1377. Table 1 lists the basic properties of the peat sample used in this experiment and the comparison with previous studies.

Figure 2 a) Dark brown paste released when squeezed, b) Indistinct plant structure left observed after squeezing

Table 1 Basic Properties of Kota Samarahan Peat

Properties	**Average Value**
Moisture Content (%)	519.35
Specific Gravity	1.63
Unit Weight (kN/m^3)	10.62
Fiber Content (%)	2.54
Organic Content (%)	94.63
Liquid Limit (%)	488.30

3. EXPERIMENTS

The peat sample is hand-mixed to a uniform paste consistency. During hand-mixing, any inclusions such as stones were removed and pre-consolidated in a cylindrical mould. The cylindrical mould is made of steel of 10.5 cm internal diameter and 41.2 cm height. The pre-consolidation is used to shape the specimen for CRS test. For this experiment, 5 kPa pre-consolidation pressure is applied. Figure 3 shows the picture and schematic diagram of the pre-consolidation setup. Sand and filter paper are placed at the bottom of the mould for adequate drainage at the bottom. The mould is filled with peat for about three-quarter of full height. Sand and filter paper are also placed at the top of the peat sample for the top drainage. A loading plate designed with bottom load hanger is hanged on the top of the sample and 5 kPa load was applied through the load hanger system. The water level in the peat moulder system is maintained to ensure full saturation throughout the moulding process.

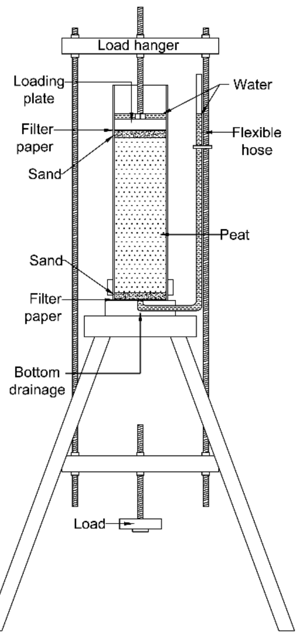

Figure 3 Schematic diagram of peat moulder cross section

Prior to each CRS variable strain rate testing, the pre-consolidated specimen is extruded and cut with the CRS mould as shown in Figure 4a to Figure 4d. The CRS specimen testing mould measures 5 cm inner diameter and 2.2 cm in height. It is made of highly polished stainless steel ring in accordance with ASTM D4186M. The internal wall of the mould is greased to minimise friction during compression. The specimen is soaked in de-aired water for about 24 hours before the consolidation test to ensure the specimen is fully saturated. The specimen is placed inside the CRS cell, covered by a set of filter paper and porous stone.

Figure 4 a) CRS ring mould and 5 kPa pre-consolidate peat, b) Peat specimen is trimmed using the CRS mould, c) Peat specimen is trimmed to absolute shape, d) Final look of peat specimen

The complete CRS setup is shown in Figure 5. The CRS apparatus is manufactured by GDS Instruments, United Kingdom. The vertical load is measured via submersible load cell (maximum loading of 8 kN) located directly on the loading plate. The vertical deformation (specimen settlement) is measured via LVDT as well as via internal motor encoder. The excess pore water pressure at the bottom of the sample is measured using two pressure transducers, i.e. the pore water transducer with pressure controller and one located adjacent to it (See Figure 1). The pressure controller enables the application of back pressure and measures the excess pore water pressure at the same time. Test control and data acquisition are done via a computer system.

The cell is filled with de-aired water about 3 cm above the sample to cover the specimen and to ensure the specimen is fully saturated throughout the test. The air vent at the top of the cell is open to the atmosphere. Note that, the few cm of water above the sample produces negligible hydrostatic pressure. Hence the pore water pressure on top of the sample can be assumed ≈ 0 kPa. The back pressure is set in the pressure controller to maintain pore water pressure at the bottom of the sample ≈ 0 kPa throughout the test. The peat specimens are tested at five different strain rates (0.5 %/ hour, 1 %/ hour, 5 %/ hour, 10 %/ hour and 20 %/ hour). All specimen preparation procedure and tests are carried out in accordance with ASTM D4186M. There are 5 samples used, where each strain rate test is represented with one sample. For comparison, three sets of conventional oedometer tests are conducted in accordance with ASTM D2435 using one-dimensional consolidation cell by ELE International with specimen size measures 7.5 cm in diameter and 2 cm in height. The tests were performed in order to verify and confirm the results from CRS tests.

4. RESULTS AND DISCUSSION

Figure 6 shows the stress-strain curves of five different strain rates. It shows that the effective vertical stress, σ'_v increases as the axial strain, ε_v increases as expected. This figure shows ε_v versus log σ'_v instead of σ'_v to adequately capture the differences in compression with change in effective stress. It is useful to show different regimes throughout the compression. As can be seen from the plot, a steep increase in σ'_v towards 10 kPa at low ε_v. Beyond 10 kPa, the log of σ'_v linearly increases with increase in ε_v. The curves deflect at about 5 kPa σ'_v which is attributed to the preconsolidation pressure applied to the specimen. About 1000 kPa σ'_v, the curves are drastically increased as the ε_v increases. The possible reason for this is that the permeability of peat decreases significantly as the macro pores close by the increase in vertical effective stress. All curves for the various strain rates used in this study follow similar pattern and magnitude. Hence, there is no clear indication of the strain rate effect on the stress-strain relationship.

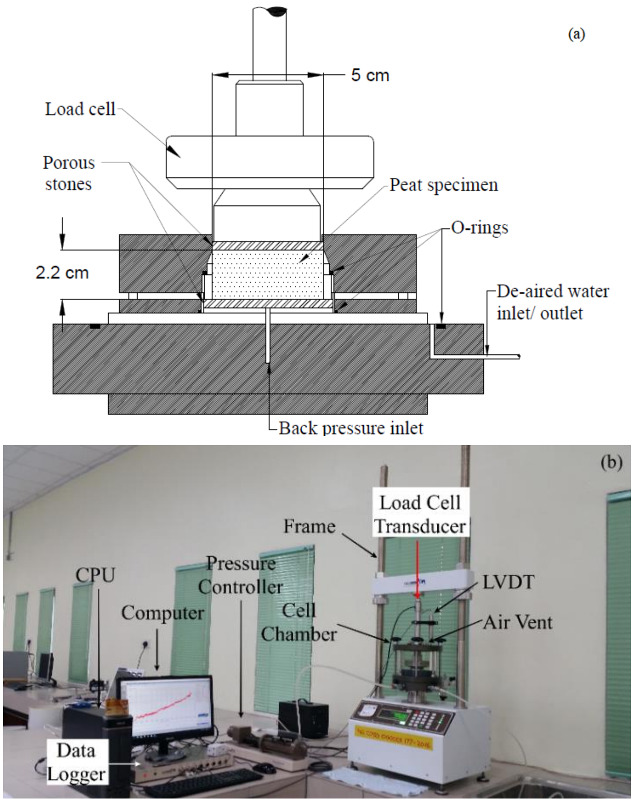

Figure 5 a) Schematic diagram of the CRS specimen cross section inside the cell chamber, b) CRS equipment setup

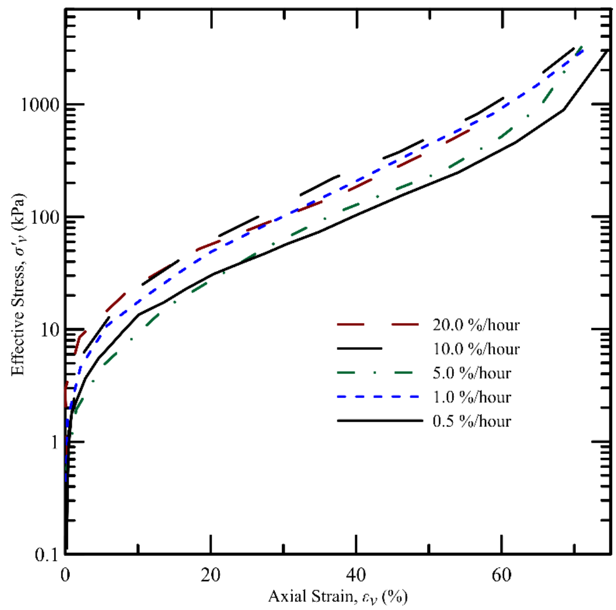

Figure 6 Stress-strain plot

Figure 7 shows the compressibility curve plot of void ratio, e versus log σ'_v to see the changes of e as the σ'_v increases. From this plot, the compressibility properties are obtained and presented in Table 2. The initial void ratio, e_0 in this study ranges from 9.992 to 10.688. The curve shows a typical over-consolidated soil behaviour with pre-consolidation pressure of about 5 kPa which is equivalent to the pressure applied during specimen preparation. The C_N value is found to be higher than 0.20, where C_N value higher than 0.2 is considered as very compressible soil (O'Loughlin & Lehane, 2003). C_c of Kota Samarahan peat for each strain rate was estimated from the normal consolidation line (NCL). The C_c for strain rate of 0.5 %/ hour, 1 %/ hour, 5 %/ hour, 10 %/ hour and 20 %/ hour are 3.730, 3.021, 3.160, 4.083, and 4.146 respectively. All of the C_c obtained from this study are not significantly different and within the lower range of C_c recorded for peat stated in the literature. Figure 8 shows a comparison of compressibility curve in this study as well as the oedometer test results. It includes data from previous studies such as Middleton peat, James Bay peat and organic clay. Figure 8 proves peat in this study has lower compressibility compare to Middleton peat and James Bay peat but higher compared to organic clay, an indication of low porosity due to low fiber content as confirmed by from the fiber content test results.

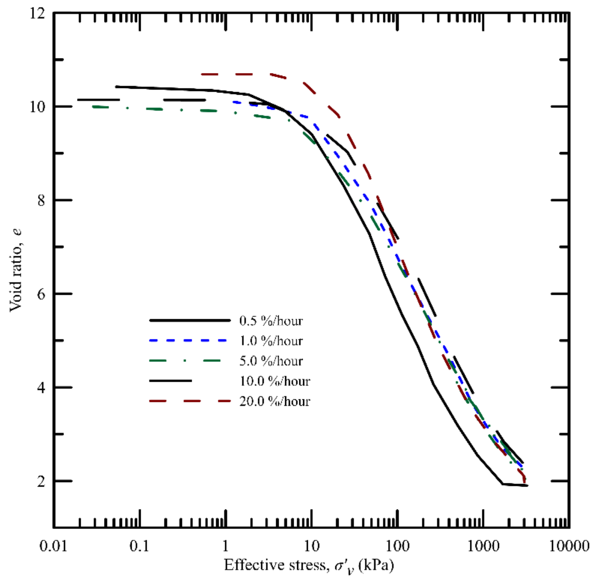

Figure 7 Void ratio versus log σ'_v from five different strain rate

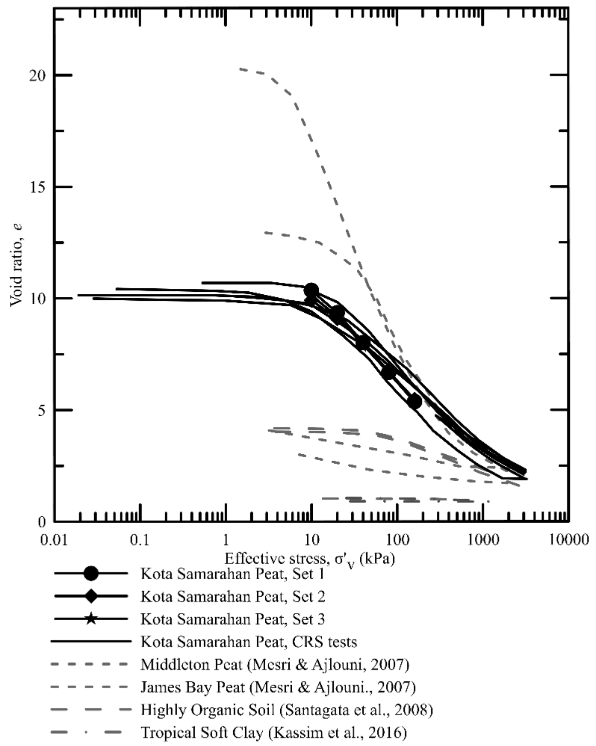

Figure 8 EOP e against log σ'_v of this study compared with other types of peat and soil

Figure 9 shows the changes in the excess pore water pressure at the base of the specimen, Δu_b with time, t for all strain rates. Δu_b at the beginning of the test for all strain rates are about zero. All strain rates show consistent Δu_b throughout the test except for 20 %/ hour strain rate where the Δu_b increases exponentially about $t > 0.3$ hour. This is due to inadequate compensation of the pressure controller to balance out the change of Δu_b. Note that the pressure controller uses feedback controlling system which does not spontaneously compensate the feedback measure.

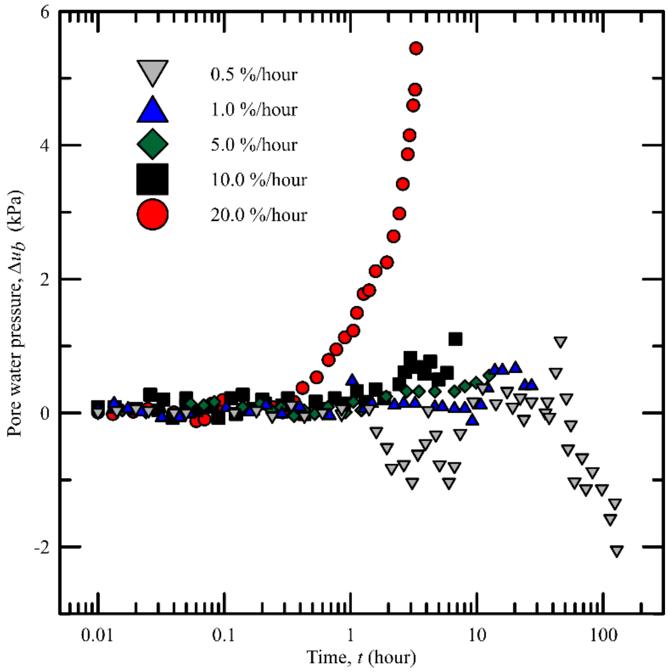

Figure 9 Pore water pressure development throughout the test at different strain rate

Figure 10 shows the plot of excess pore water pressure ratio, $\Delta u_b/\sigma_v$ versus σ'_v for all the strain rates. The overall trend of the curves shows that the $\Delta u_b/\sigma_v$ gradually converge towards zero as the σ'_v increases. The ASTM recommends that a strain rate should generate $\Delta u_b/\sigma_v$ ratio between 3 % and 15 % at the bottom of the specimen. In practice, the equivalent strain rate usually falls below 3 % and much lesser for soft soils. For the present experiment, the peak $\Delta u_b/\sigma_v$ is generated at the initial stage of the test for all strain rates and there is no evidence of $\Delta u_b/\sigma_v$ building up to the peak. The peak $\Delta u_b/\sigma_v$ for tests at the strain rate of 1 %/ hour to 20 %/ hour is within 3 % to 15 % range as suggested by ASTM D4186M while that of 0.5 %/ hour falls below 3 %. The high initial $\Delta u_b/\sigma_v$ observed in this experiment is connected to the delay in the equalisation of excess pore water pressure. The high reading is recorded by the pressure controller before the compensation/ equalisation of what is measured by the pressure transducer. The faster the strain rate the more difficult it is for the excess pore water pressure to equalise and the higher the initial $\Delta u_b/\sigma_v$. Since the back pressure for this test is set to zero, when there is increment or decrement of the back pressure, the pressure pump takes time to compensate or equalise the gain or loss of the pressure. The pump is driven by using electrical motor where it receives feedback (information of pore water pressure) from the pressure transducer (from the pressure controller). The information from the pressure transducer is sent to the computer and the computer commands the motor to move the pump to compensate the pore water pressure sand maintain the set pressure. This feedback mechanism is not immediate and takes some time. Such limitation would affect the strain rate where at faster the strain rate makes it more difficult for the excess pore water pressure to equalise and the higher the initial $\Delta u_b/\sigma_v$.

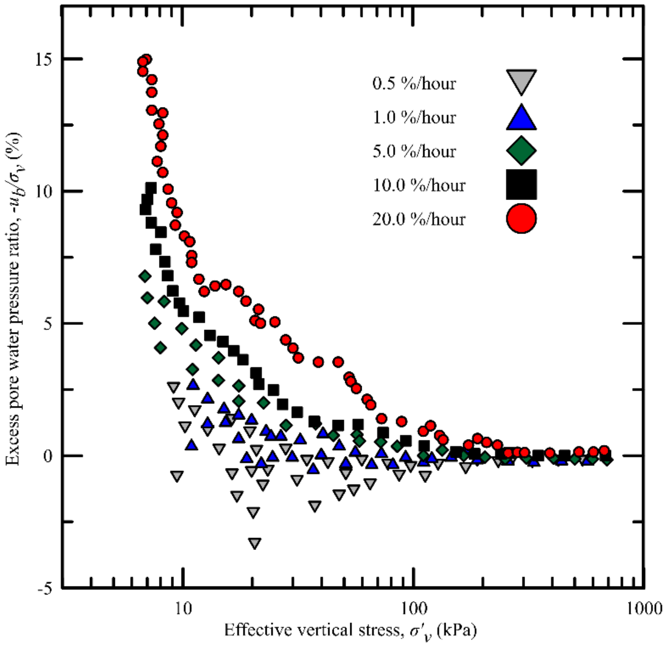

Figure 10 Pore water pressure ratio-strain trend throughout CRS test at different strain rate

5. CONCLUSIONS

This paper presents the compressibility behaviour mechanism of reconstituted sapric tropical peat by imposing zero back pressure in CRS test including the index properties. The following is the list of findings established:

1. There is no difference in compressibility among tests at strain rates of 0.5 %/ hour to 20 %/ hour in CRS test.
2. At 20 %/ hour of strain rate, the $\Delta u_b/\sigma_v$ is still lower than 15% as reported by ASTM D4186M. Therefore, using 20 %/ hour of strain rate is recommended to avoid creep and to expedite the testing.
3. For 20 %/ hour strain rate, it appears that the Δu_b starts to build up due to slow compensation from the pressure controller (i.e. equipment limitation).
4. C_c values obtained from this study are found to be at the lower range of C_c reported, and the C_c values obtained from this study are within the range of C_c gained from the conventional oedometer.
5. The permeability of sapric peats decreases dramatically which is due to the constricted flow channels.

6. ACKNOWLEDGEMENT

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