LONG TERM COMPRESSION BEHAVIOR OF FIBROUS PEAT

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Abstract: This paper discusses a long term compression behavior of fibrous peat, analyzed based on data obtained from consolidation test performed in Rowe cell with excess pore water pressure measurement. The preliminary test results show that the peat used in this study is classified as fibrous peat with low to medium degree of decomposition and of very high organic and fiber contents which are typical of peat found in Peninsular Malaysia. The results of consolidation test show that the fibrous peat has a high compressibility with primary compression index of 3.15 and significant secondary compression stage which is not constant with the logarithmic of time. The secondary compression started as early as 65% degree of primary consolidation. The study showed that the consolidation test with pore water pressure measurement using Rowe cell is advantageous because it enables the observation of the large deformation and better assessment of the long term compression behavior of fibrous peat. The separation of primary and secondary consolidation is very important for the evaluation of long term compressibility behavior of fibrous peat.

Keywords: *fibrous peat; compression behavior; pore-water pressure measurement*

Abstrak: Kertas kerja ini membincangkan sifat kebolehmampatan tanah gambut berdasarkan hasil ujian pengukuhan menggunakan sel Rowe dengan pengukuran tekanan air liang lebihan. Ujian piawaian makmal menunjukkan bahawa tanah yang digunakan dalam kajian ini boleh dikelaskan sebagai gambut gentian dengan darjah penguraian rendah ke sederhana serta kandungan organik dan gentian yang tinggi. Ia merupakan jenis tanah gambut yang biasa ditemukan di Semenanjung Malaysia. Hasil ujian pengukuhan menunjukkan bahawa kebolehtelapan mula tanah adalah tinggi dengan nilai kebolehtelapan malar 3.15, dan mampatan sekunder yang cukup besar dengan kelajuan yang tidak malar terhadap logaritma masa. Mampatan sekunder bermula bila tanah mencapai darjah pengukuhan 65%. Kajian menunjukkan bahawa pengujian kebolehmampatan dengan menggunakan sel Rowe dan pengukuran tekanan air liang lebihan lebih baik kerana ia membolehkan penyiasatan tindak balas tanah terhadap bebanan pada kadar terikan yang tinggi hingga membenarkan penyelidikan sifat kebolehmampatan tanah untuk masa yang lebih lama. Pemisahan pemampatan primer dan sekunder sangat penting bagi evaluasi sifat pemampatan tanah gambut gentian.

Kata kunci: *gambut gentian; sifat kebolehmampatan; pengukuran tekanan air liang lebihan*

1.0 Introduction

Peat is identified as a problematic soil because of its low shear strength and unusual compression behavior. In general, the compressibility of a soil consists of three stages, namely initial compression, primary consolidation, and secondary compression. While initial compression occurs instantaneously after the application of load, the primary consolidation and secondary compression are time dependent. The initial compression is due to the compression of small pockets of gas within the pore spaces and the elastic compression of soil grains. The one-dimensional theory of consolidation developed by Terzaghi in 1925 carries an assumption that primary consolidation is due to dissipation of excess pore water pressure caused by an increase in effective stress whereas secondary compression takes place under a constant effective stress at a slower rate after the completion of the primary consolidation. Thus the time-compression curve derived from consolidation test follows the Type 1 (“S”) curve as shown in Figure 1.

The compression behavior of fibrous peat is different from that of clay soil. It is controlled by several factors including the initial water content, void ratio, initial permeability, fiber content and arrangement, and the condition in which the fibrous peat is deposited. In tropical region, peat forms a doomed deposit comprises two layers underlain by a thick clay layer. The upper layer consists of fibrous peat containing long and slender roots and rootlets, while the bottom is a dense woody peat derived from the decomposition of the vegetation (Cameron, *et al*. 1989).

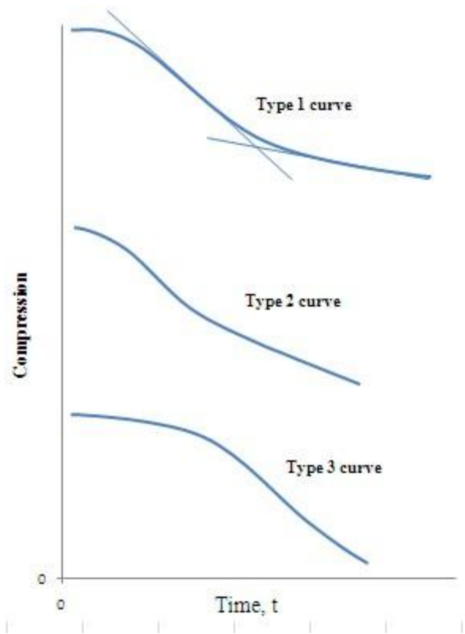

Figure 1: Types of compression versus logarithmic of time curve derived from consolidation test (Leonards and Girault, 1961)

The compressibility of fibrous peat occurs in three stages: primary consolidation, secondary compression and tertiary compression. The primary consolidation of the fibrous peat is very rapid; however, the secondary compression is generally more significant because the time rate is much slower than the primary consolidation. The secondary compression occurs due not only to the compression of particles, but also the plastic yielding of solid material (Samson and La Rochelle, 1972). Tertiary compression was reported by several researchers (e.g. Candler and Chartres, 1988; Fox et al., 1992), but other researchers (e.g. Edil and Dhowian, 1979; Hansbo, 1991; Fox and Edil, 1994) argued that this part of compression can be neglected because it generally started after the design life of structures.

The time-compression curves derived from results of one-dimensional consolidation test on fibrous peat usually resemble the Type 2 curve (Figure 1) in which the primary consolidation is very rapid and secondary compression does not vary linearly with logarithmic of time. Therefore the quantification of secondary compression based on conventional compression–logarithmic of time method proposed by Cassagrande (1936) which was later extended by Dhowian and Edil (1980) frequently under-estimates the settlement. Sridharan and Prakash (1998) proposed another method for identifying the beginning and rate of secondary compression based on logarithmic of compression-logarithmic of time (log δ - log t) curve. The advantage of this method is that the logarithmic of the secondary compression is found to be linear over a wider extend of time, thus the method takes care of the nonlinearity in the rate of secondary compression; however, the method also relies on the inflection point to identify the end of primary consolidation. In some cases, the time compression curve for fibrous peat follows Type 3 curve (Figure 1) where no inflection point was identified, thus the end of primary consolidation (t_p) cannot be predicted by the above methods.

Robinson (1999) pointed out that the end of primary consolidation is actually the time when full dissipation of excess pore water pressure is achieved; thus, measurement of excess pore water pressure during consolidation test is required. His observation showed that the excess pore water pressure dissipation is completed earlier than the time predicted from the inflection point of the settlement curve. Further analysis by Robinson (2003) supported the argument made by previous researchers that the secondary compression of some soils actually starts during the dissipation of excess pore water pressure from the soil.

Terzaghi's one dimensional consolidation theory stated that the compression during primary consolidation is linearly correlated with the dissipation of excess pore water pressure. Conversely, the actual curve derived from laboratory consolidation test on peat soil was not actually follows a straight line because the settlement was actually due to the combination of excess pore water pressure dissipation on primary consolidation and creep or secondary compression. A method for separating the primary consolidation and secondary compression that occur during the consolidation process based on time-compression and the time-excess pore water pressure curves was proposed by Robinson (2003).

If the primary consolidation and secondary compression were separated in the time-compression curve, the *e-log* p' curve can be constructed for primary consolidation only (Fox, 2003). The curve is required for the determination of compression index (c_c) and pre-consolidation pressure (σ'_c) of the soil.

This paper focuses on the evaluation of the long term compression behavior of fibrous peat based on data obtained from consolidation test performed in Rowe cell with excess pore water pressure measurement. Data was analyzed based on the time-compression curve, excess pore water pressure curve, and consolidation curve derived from the test results.

2.0 Methodology

The peat samples for this study were obtained in West Johor, Malaysia. Eighteen samples were retrieved by block sampling method from six clusters of three sampling points. The distance between clusters was about 3m while the distance between sampling point was 1m. In-situ measurement of water content was not possible; thus, sufficient care was taken during the sampling of the peat in order to maintain the natural water content. Three samples were acquired by piston sampler for water content determination in laboratory. Field vane test was performed for the assessment of in-situ undrained shear strength of the peat.

Physical and chemical properties such as natural moisture content, specific gravity, initial void ratio, unit weight, and acidity were determined to establish the basic characteristics of the soil. The soil was classified based on von Post or degree of humification, fiber content, organic content, and ash content. All tests were performed in accordance with the British (BS) and U.S. (ASTM) Standards.

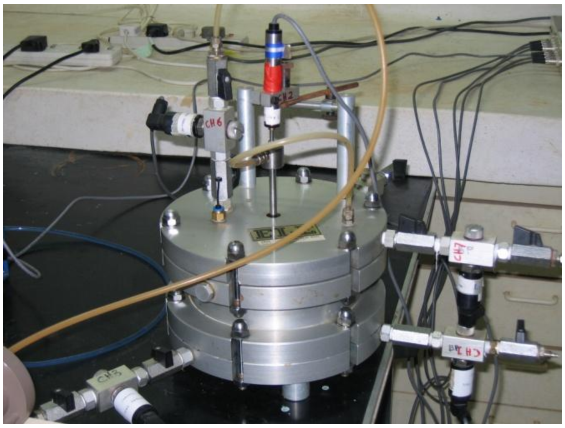

Figure 2: Rowe consolidation cell used in this study

Large strain consolidation tests were performed using Rowe consolidation cell (Figure 2) with internal diameter of 151.4 mm and height of 50 mm. Each sample was subjected to large strain consolidation pressures of 25, 50, 100, and 200 kPa or load increment ratio (LIR) of one. Drainage was allowed at the top and bottom plates, while pore-water pressure was measured at the center of the base. The tests were performed according to the procedure suggested by Head (1982).

The time-compression and excess pore water pressure curves derived from Rowe consolidation test were analyzed using method proposed by Robinson (2003) in order to develop the compression-degree of consolidation curve to identify the beginning of secondary consolidation (t_p). The primary consolidation and secondary compression were separated in order to assess the coefficient of consolidation (c_v) and secondary compression index $m = \Delta\log\delta_s/\Delta\log t$ as proposed by Sridharan and Prakash (1998) or $\delta_a = \Delta\delta_s/\Delta t$ as proposed by Robinson (2003). Both methods give the same values of secondary compression index.

Besides the time-compression curve, a graph relating the void ratio at the end of each loading stage with the effective pressure on logarithmic scale (e-log p') was plotted for a complete set of consolidation test data. In this case, the curve was plotted for primary consolidation only whereby the void ratio is corrected by eliminating the creep occurred after the completion of primary consolidation. The curve was used to obtain compression index, c_c and pre-consolidation pressure (σ'_c). The effect of initial compression was minimized during the preparation of the test specimen and the consolidation test by Rowe cell.

3.0 Basic Properties and Classification of Fibrous Peat

Observation made at site showed that the peat is categorized as deep peat with thickness of more than 5m. Groundwater table presents at depth less than 1m at the time of sampling. Visual identification showed that the peat is dark brown, very soft, and contains a large amount of fiber. Plant structures such as roots are easily recognizable from the soil, and this can be attributed to incomplete decomposition of organic matters. The texture is coarse which results in high initial permeability. The in-situ shear strength (s_u) obtained by field vane test is 10 kPa with sensitivity of 6.

The basic properties and classification of fibrous peat is summarized in Table 1. Except for some extremities, all data obtained from this study are within the range published for Malaysian peat (Muttalib et al., 1991 and Huat , 2004).

Table 1. Basic Properties of the Peat Soil

	Parameters	Results	Published data (ranges)
Index Properties	Natural water content (%)	608	200 – 700
	Bulk unit weight (kN/m^3)	10.02	8.30 – 11.50
	Specific Gravity (G_s)	1.47	1.30 – 1.80
	Initial void ratio (e_o)	9	3 – 15
	Acidity (pH)	3.2	3.0 – 4.5
Classification	Degree of decomposition (von Post scale)	H_4	H_1- H_4
	Organic content (%)	97	> 90
	Fiber content (%)	90	> 20

4.0 Compressibility

The typical time-compression curve obtained from consolidation test is shown in Figure 3. The shape of the compression curve resembles the Type 2 curve (Figure 1) which is typical of compression of peat soil. The shape of the time-compression curve indicates that the deformation process of fibrous peat deviates from the simple model used in Terzaghi's consolidation equation, which is the basis for the Cassagrande and Taylor's evaluations of primary consolidation and the estimation of the coefficient of consolidation.

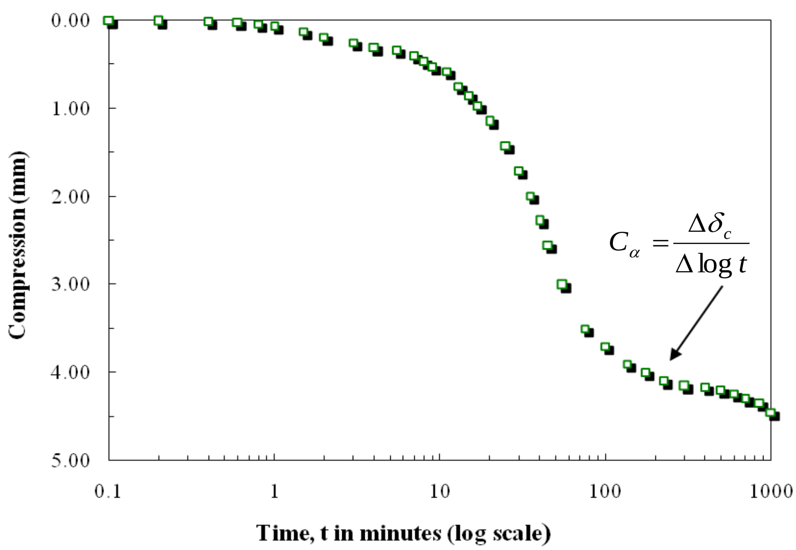

Figure 3: Typical time compression curve from consolidation test

Evaluation of the time-compression curve shown in Figure 3 cannot be made based on conventional method because the curve does not give a clear indication of an inflection point where the primary consolidation is assumed to end and the secondary compression is assumed to start. The curve indicates that the primary consolidation is dominant in term of magnitude and the rate is high. The secondary compression occurred at a slower rate and is non-linear with logarithmic of time. This part of the compression, even though less significant than the primary consolidation in term of magnitude, could be very important in term of the design life of a structure. The secondary compression may have started during the process of excess pore water pressure dissipation.

The typical time-excess pore water pressure curve derived from consolidation test is presented in Figure 4. As suggested by Robinson (1999), the time of the completion of primary consolidation can be easily identified from the curve. In this case, the completion of excess pore water pressure dissipation (t_{100}) is about 30 minutes. However, in Figure 3, the inflection at two points, before and after t_{100} is not clear. Robinson (1997) suggested that the secondary compression of fibrous peat started before t_{100}; hence, the earlier inflection point may indicate the beginning of the secondary compression.

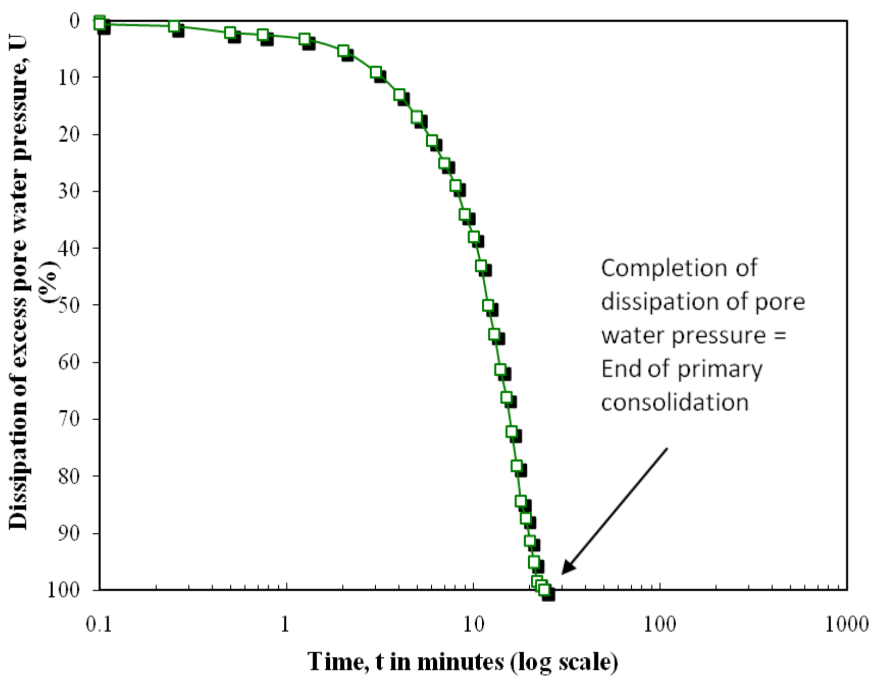

Figure 4: Typical time-excess pore water pressure curve from consolidation test

As mentioned previously, the relationship between the primary consolidation and dissipation of pore-water pressure form a straight line. Therefore, Robinson (2003) suggested that the beginning of secondary compression (t_p) can be identified as the time when the compression-degree of consolidation curve deviates from the straight line and this occurs when the degree of primary consolidation reaches U_p%. The occurrences of primary consolidation and secondary compression beyond this point should be separated to form a primary consolidation and secondary compression curves. Figure 5 shows the identification of the degree of consolidation where the secondary compression is actually started.

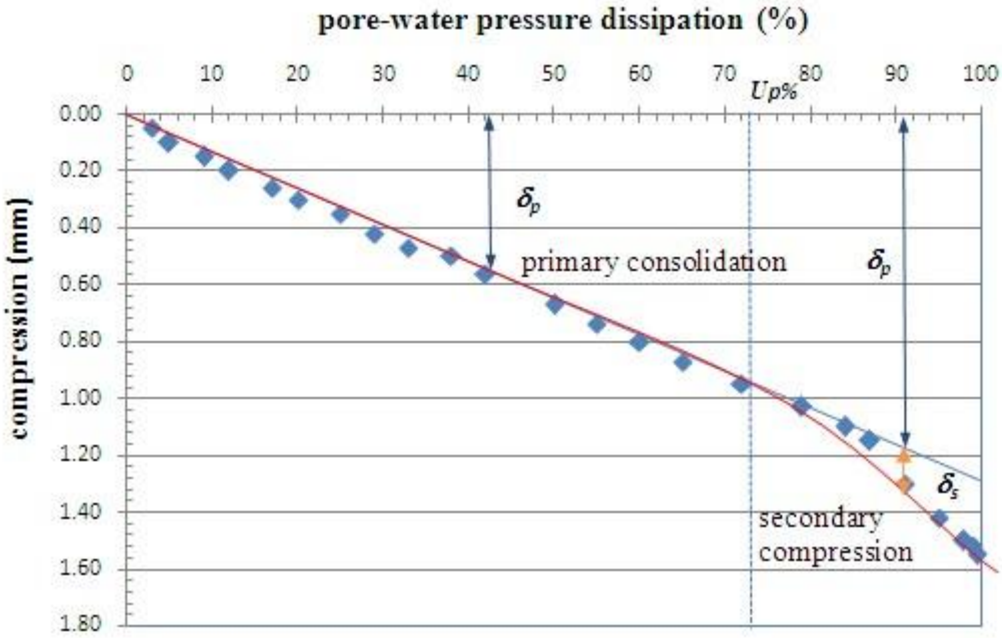

Figure 5: Typical compression-degree of consolidation curve from consolidation test

The primary consolidation curve was used for the evaluation of the coefficient of consolidation (c_v), while the secondary compression part was used for evaluating the secondary compression index (δ_a). Figure 6 shows the time-compression curve generated for primary consolidation only while Figure 7 shows the estimation of secondary compression index based on time-compression curve, both in linear scale.

Table 2 summarizes the results from consolidation test which indicate that the higher the consolidation pressure, the faster the dissipation of excess pore water pressure, and the shorter the time needed for primary consolidation. The beginning of the secondary compression (t_p) decreases with increasing consolidation pressure but the degree of consolidation where the secondary compression stared (U_p) increases as the consolidation pressure increases.

Figure 6 : Time-compression curve for primary consolidation only

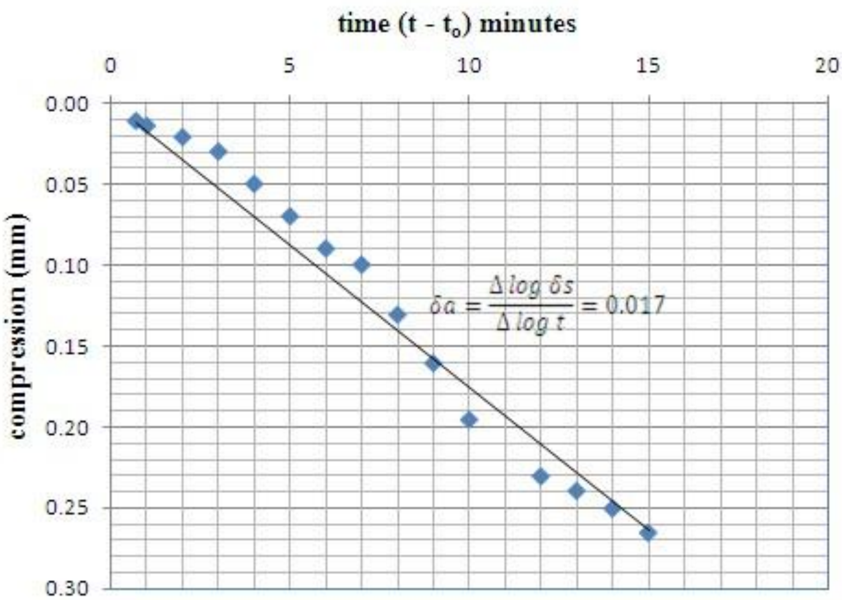

Figure 7 : Determination of index of secondary consolidation (δ_a)

Table 2: Compressibility characteristics based on time-compression curve

Consolidation pressure (p', kPa)	End of primary consolidation (t_{100}, minutes)	The beginning of secondary compression (t_p, minutes)	Degree of consolidation (U_p, %)	Coefficient of consolidation (c_v , m^2/year)	$\delta_a = \Delta\delta_s/\Delta t$
25	27.67	19.83	61.67	5.689	0.0109
50	25.83	17.67	65.00	4.947	0.0124
100	23.50	15.83	69.00	4.179	0.0157
200	23.00	14.33	70.50	3.259	0.0211

Table 2 indicates that c_v decreases with increasing consolidation pressure. This finding is in agreement with the theory of consolidation, which stated that the coefficient of rate of consolidation decreases with increasing consolidation pressure (Leonards and Girault, 1961). As shown in Figure 3, the secondary compression index C_α is not constant. However, the curve can be linearized by plotting both δ_s and time in logarithmic scale as suggested by Sridharan and Prakash (1998) or in linear scale as suggested by Robinson (2003). The linear form enables the determination of δ_a value which increases with increasing consolidation pressure. The results are not in agreement with the popular theory which suggests that the coefficient of secondary compression is constant (Mesri and Godlewski, 1977) but support the findings of Lea and Browner (1963) and Fox et al. (1992) who found some correlations between coefficient of secondary compression and the consolidation pressure.

The *e*-log p' curve derived from the consolidation test under different consolidation pressures was plotted in Figure 8 whereby the time-consuming curve has been generated for total compression and for primary consolidation only. The figure shows that the compression index (c_c) for primary consolidation is 3.15, slightly lower than the slope evaluated based on total settlement (5.0).

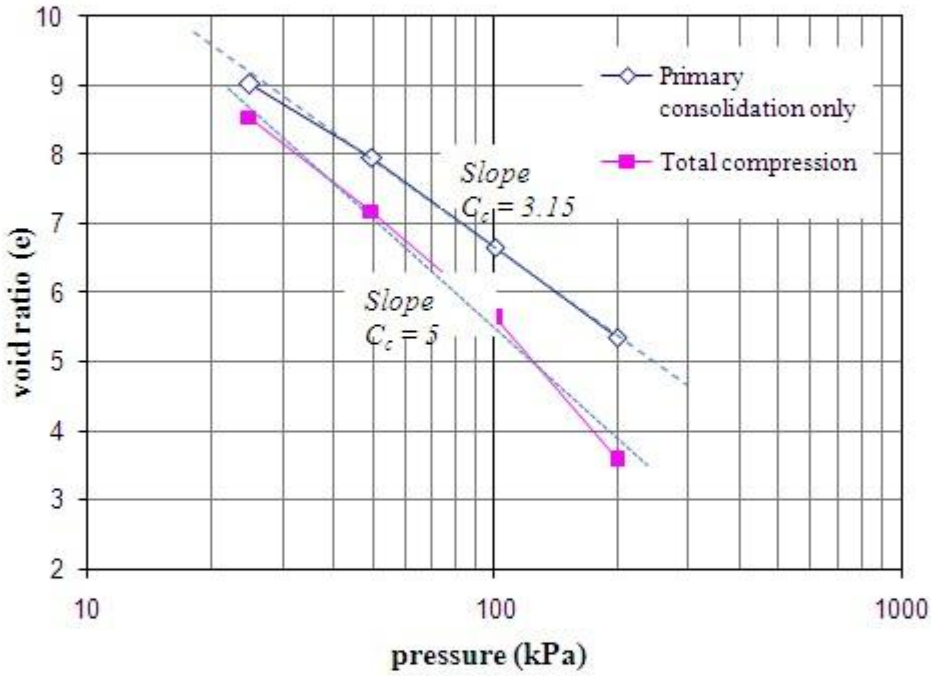

Figure 8: Typical *e*-log *p'* curve for determination of compression index

5.0 Conclusions

The peat used in this study can be classified as fibrous peat with low degree of decomposition (H_4 according to Von Post Scale) and very high organic and fiber content which is the typical peat found in the western part of Peninsular Malaysia. Several conclusions can be derived for the long term compression behavior of the peat:

a. The compression curve resembles the typical compression of peat soil in which there is no clear indication of an inflection point. The primary consolidation is dominant in terms of magnitude, but the rate is high. The secondary compression varies with consolidation pressure and is non-linear with time. The secondary compression started as early as 65% primary consolidation. The beginning of secondary compression (t_p) is 18 minutes while the completion of primary consolidation (t_{100}) is 26 minutes. The coefficient of rate of consolidation (c_v) obtained ranges from 5.69 to 3.26 m^2/yr for a range of pressure from 25 to 200 kPa.

b. The compression index (c_c) for primary consolidation is 3.15 while the coefficient of secondary compression that was estimated based on secondary compression-time curve, both in logarithmic scale, gave δ_a values from 0.0102 to 0.0304 for consolidation pressure of 25 to 200 kPa.

c. The separation of primary and secondary consolidations is very important for the evaluation of long term compressibility behavior of fibrous peat because the conventional evaluation of settlement based on the time-compression curve may result in over-prediction of primary consolidation and under-prediction of secondary consolidation.

6.0 Acknowledgement

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