Back pressure saturation techniques for tropical fibrous peat in constant rate of strain consolidation tests

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1 Introduction

Constant rate of strain (CRS) consolidation test was firstly introduced by Hamilton & Crawford [1]. This test applies a continuous load to a soil specimen at a constant rate of strain, and the soil stress responses are measured throughout the process. Compared to conventional load increment tests, the CRS test offers several advantages, including a significantly short duration to complete the test, a more comprehensive dataset of stress-compression relationships, and improved data acquisition. Furthermore, the application of CRS test for soft soil can prevent the specimen from squeezing out along the inner surface of a consolidation ring.

Despite these advantages, comprehensive studies on the application of the CRS test have mainly focus on clay soils. Conversely, its application to tropical fibrous peat remains limited due to the lack of specific guidelines for conducting CRS consolidation tests on this soil type. For instance, the specific procedure for applying back pressure to saturate the tropical fibrous peat specimen is not stated in ASTM D 4186 [2]. This procedure also cannot be found in the previous research of application CRS test for peat [3–5]. Tropical fibrous peat typically exhibits a high void ratio, ranging from approximately 6 to 11. This value indicates a considerable of void spaces, including both macropores and micropores that necessitate adequate saturation prior to testing. Consequently, the absence of a proper saturation procedure may result in inconsistent stress–compression relationship curves in constant rate of strain (CRS) testing of tropical fibrous peat.

According to the addressed problem, the present study aims to describe a method for applying a proper back pressure for tropical fibrous peat specimen in CRS test. Tropical fibrous peat samples were collected from Palangkaraya, Central Kalimantan, Indonesia. The specimens were subjected to back pressures ranging from 50 kPa to 125 kPa and then loaded at various strain rates. The resulting curves of normalized void ratio and logarithmic effective stress relationship were then evaluated. In addition, conventional load increment tests were also conducted to validate the CRS test result.

2 Material and testing procedures

A tropical fibrous peat used in this study was collected from Bereng Bengkel Village, Palangkaraya, Central Kalimantan Indonesia. The undisturbed samples were collected using 4-inch PVC tubes at a depth of 1 meter beneath the soil surface, where the water table was located. Each tube was sealed at both ends to keep the natural water content of the sample. The average values of the specimen's physical properties are shown in Table 1. The testing procedure were conducted in accordance with ASTM D2974-20 [6], ASTM D1997-20 [7], and the Peat Testing Manual [8]. According to ASTM D 4427 [9] the peat studied is classified as sapric peat (F_c < 33%). The parent material of the peat studied was identified visually and classified as woody peat.

A series of CRS tests were carried out using undisturbed specimens. The CRS testing apparatus used in this study is shown in Figure 1. All specimens were carefully inserted into the consolidation ring, and any coarse fibers crossing the ring were trimmed with a razor blade. The specimens were then placed in the consolidometer ring and the chamber was filled with water. The specimen saturation process for the CRS test was conducted as follows:

- The water supply reservoir valve was turn into closed position.
- The back pressure was increased by approximately 5 kPa at each increment. It should be noted that the void ratio of the specimens is 8.347 (very soft); therefore, the application of excessive back pressure could result in undesirable prestressing or compression of the specimens. Once the pore pressure at the base of the specimens equal to the cell pressure, only the macropores may have been saturated. Consequently, an additional waiting period of 15–30 minutes was required to ensure complete saturation of the micropores.
- The back pressure was gradually increased using the same increment as previously until targeted total magnitudes were reached, i.e., 50 kPa, 100 kPa, and 125 kPa.
- The specimens were left under these conditions for approximately 20 hours to allow full equalization of the system pressure, completing the saturation procedure.
- The strain rate was selected according to the previous study conducted by Prativi et al. [10], which suggested a strain rate range of 0.04–0.5% min^{-1} for coarse fibers content of 17.35% (Table 1).
- The loading process finished once a total stress of 200 kPa was achieved.

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Table 1. Physical properties of tropical fibrous peat studied.

No.	Soil Properties	Unit	Result
1	Organic content, O_c	%	92.77
2	Ash content, A_c	%	7.23
3	Unit weight	kN/m^3	10.15
4	Water content, w_c	%	569.66
5	Void ratio, e		8.347
6	Fiber content, F_c	%	31.35
7	Spesific Gravity		1.41
8	Fiber size distribution		
	- foreign material	%	1.72
	- coarse fiber	%	17.35
	- medium fiber	%	13.95
	- fine fiber	%	66.97

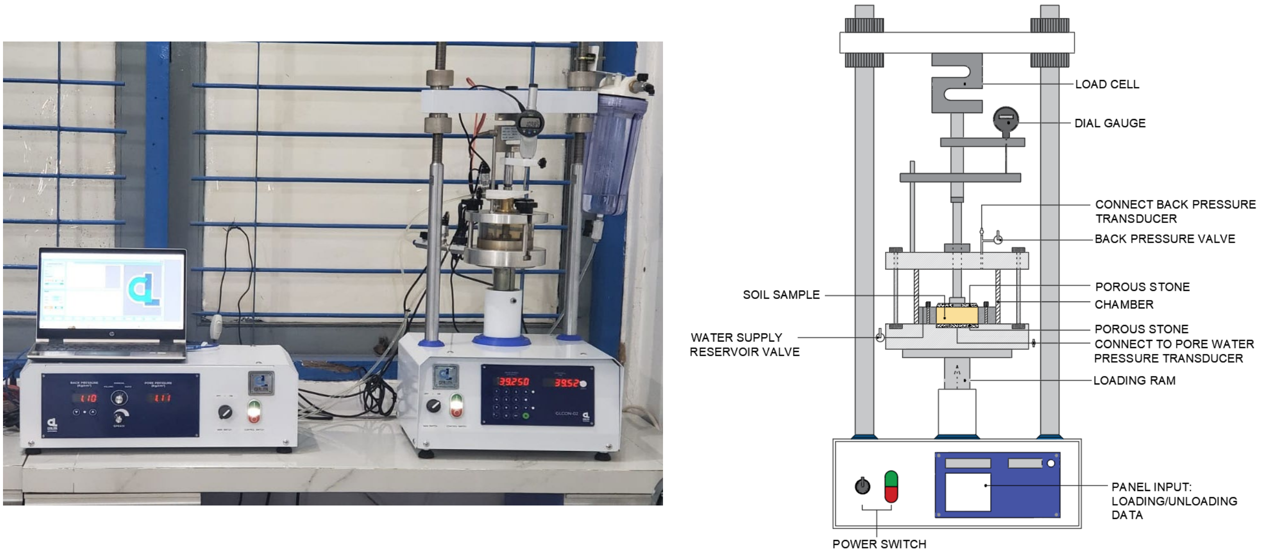


Figure 1. Constant strain rates (CRS) apparatus used in this study.

Additionally, conventional load increment tests were conducted to validate the effective stress vs normalized void ratio curve obtained from the CRS tests. The specimens were initially loaded with 12.5 kPa, and the load was increased each 24 hours using a load increment ratio (LIR) of 1. Loading of specimens continued until a total stress of 200 kPa was reached.

3 Result and discussion

Figure 2 illustrates the relationship curves between normalized void ratio (e/e_0) and effective stress (σ') for specimens prepared under different back pressures of 50 kPa, 100 kPa, and 125 kPa. All specimens were loaded at a constant strain rate of 0.25%/min. The result shows that specimens prepared with back pressure of 100 kPa and 125 kPa exhibit nearly coincident curves, indicating similar compressibility behavior. In contrast, the specimens prepared with a back pressure of 50 kPa shows vertical deviation from the other two curves. Despite this deviation, the 50 kPa specimen displays a comparable gradient once the effective stress exceeds 100 kPa. These observations indicates that the magnitude of applied back pressure significantly influences the shape of normalized void ratio (e/e_0) vs effective stress (σ') curve, particularly during the early stage of loading. Applying a back pressure of at least 100 kPa leads to improved specimen saturation and more consistent compressibility behavior.

Figure 3 evaluates the influence of back pressure on the relationship between normalized void ratio (e/e_0) and effective stress (σ') under different strain rates. Figure 3a shows that the compression curves of specimens saturated under a back pressure of 50 kPa are not consistent with each other. In contrast, specimens saturated under a back pressure of 100 kPa exhibit similar compression curves across different strain rates. These results indicate that applying a back pressure of 100 kPa provides adequate specimen saturation, as evidenced by the coincident compression curves within the selected strain rates range. This back pressure is low compared to that required for cohesive soils, which typically need back pressures ranging from 400 to 1000 kPa. The application of higher back pressure to further improve specimen saturation is not recommended, as the process is time-consuming due to the back pressure increments being limited to 5 kPa in this study.

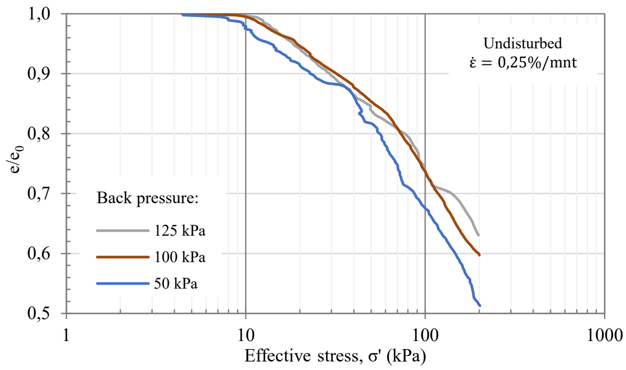
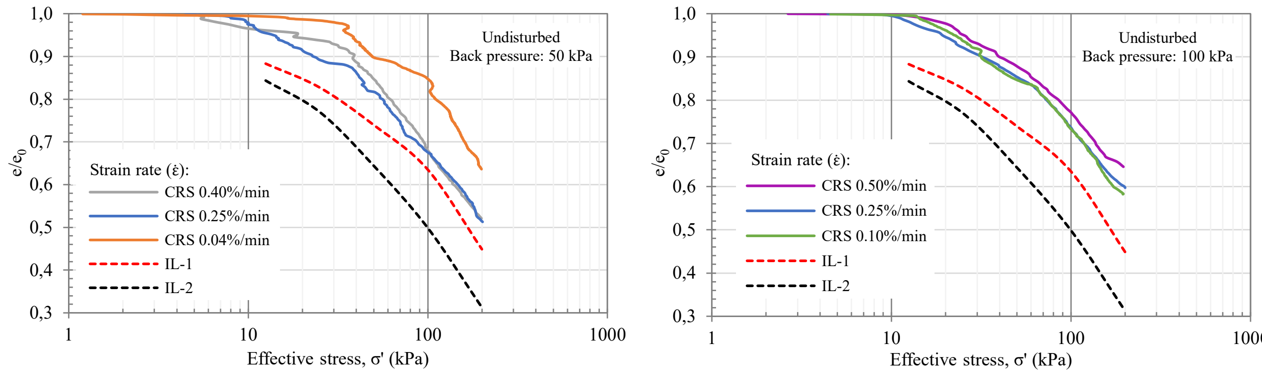


Figure 2. The influence of back pressure magnitude on e/e_0 vs. log σ' curve shapes.



(a) (b)

Figure 3. Comparison of e/e_0 vs. log σ' curves for specimens loaded at various strain rates under a back pressure of: (a). 50 kPa; (b). 100 kPa.

Table 2. Comparison of compression parameters obtained from CRS and IL tests.

Code	Constant rate of strain (CRS)				Incremental load (IL)	
	Back pressure of 50 kPa		Back pressure of 100 kPa			
	σ_{pc}' (kPa)	C_c	σ_{pc}' (kPa)	C_c	σ_{pc}' (kPa)	C_c
0.5%/min			41.0	2.98		
0.4%/min	77.0	8.39				
0.25%/min	46.5	4.74	35.0	3.24		
0.04%/min	39.0	5.38				
0.10%/min			37.0	3.62		
IL-1					54	4.92
IL-2					39	2.38
Average	54.2	6.17	36.0	3.43	46.5	3.65
STDEV	20.13	1.95	1.41	0.27	10.61	1.80

Compared with the incremental loading (IL) method using a conventional oedometer test, the curves in Figure 3 show that the CRS specimens exhibit a smaller compression magnitude, leading to a significant vertical discrepancy between the two methods. This discrepancy arises because the plotted compression data for the IL method were obtained from the final readings at each incremental load stage (i.e., 24 hours), which include both primary and secondary compression. For peat specimens, primary compression under incremental loading can be completed in less than one minute, depending on the fiber and coarse fiber content, and is followed by significant secondary compression [11–12]. As a result, the compression measured in IL tests is greater than that obtained from CRS tests [10].

Preconsolidation stress (σ_{pc}') and primary compression index (C_c) are important compression parameters for soft soils, determined from the relationship between void ratio and logarithmic effective stress. However, the term "preconsolidation stress" is not appropriate for peat, as its formation does not occur under normal sedimentation conditions, and no widely accepted method exists to determine this parameter [13]. Moreover, the σ_{pc}' value of peat may be influenced by fiber characteristics, including parent material, fiber content, and degree of decomposition. Nevertheless, in this study, σ_{pc}' and C_c were determined using the Casagrande method to quantitatively assess the variability between compression parameters obtained from CRS and IL tests, as summarized in Table 2. The results show that CRS specimens saturated under 50 kPa exhibit the greatest variability, with standard deviations (STDEV) of 20.13 for σ_{pc}' and 1.95 for C_c. In contrast, specimens saturated under 100 kPa show the smallest variability, with corresponding values of 1.41 for σ_{pc}' and 0.27 for C_c. These findings indicate that a back pressure of 100 kPa in CRS testing is sufficient to provide consistent compression parameters, even when compared with IL test results.

4 Conclusion

Based on CRS tests conducted on tropical fibrous peat collected from Bereng Bengkel Village, Palangkaraya, Central Kalimantan, Indonesia, several conclusions can be drawn:

1. A back pressure of 100 kPa is found to be optimal for achieving adequate saturation of tropical fibrous peat specimens, as it results in consistent normalized void ratio (e/e_0) vs effective stress (σ') relationship curves.
2. The curves of the relationship between normalized void ratio (e/e_0) and effective stress (σ') for well-saturated tropical fibrous peat CRS specimens coincide across a constant strain rate range of 0.10–0.50%/min and are comparable to those obtained from the conventional incremental load (IL) test.
3. The preconsolidation stress (σ_{pc}') and primary compression index (C_c) for CRS specimens saturated under 100 kPa of back pressure show the smallest variability when subjected to loading at various constant strain rates.

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