Compressive Behavior of Bagansiapiapi-Riau Peat in Indonesia

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ABSTRACT

The compressibility of peat soil will affects its bearing capacity, stability of construction, and stability of the structure built on top of it. This study aims to determine the compressibility of peat soil through a series of loading in consolidation rig and a small-scale model in the laboratory. The samples of the peat soil were collected from Bagansiapiapi-Riau in Indonesia which had 99% organic content, 35% fiber content, and 971% water content. The results from consolidation test shows that compressibility of peat is dominated by its long-term secondary consolidation. Compressibility index (*Cc*) of the soil is affected by the loading method and period. Compressive behaviour of peat during loading-unloading method is generally larger than during load increment duration of 24 h and it is faster than the load increment duration of a week. This information can be used in order to get a prediction of the settlement that will occur below the embankment. Comparison was made on each of the settlement measured during the experiment. It was found that the values from hyperbolic method are around 1,08 times higher than Asaoka's method. The measured settlement curves from this study are in agreement with Asaoka's prediction method.

KEYWORDS: peat, compressibility, consolidation, settlement, embankment.

INTRODUCTION

Based on the occurrence, peat deposit is a mixture of fragments of organic material from decomposed plant remains [9]. Its color and odor can be used to identify the presence of peat soil in the field [6]. Fibrous peat has a hollow structure which mostly occupied by water and very compressible. Compressibility of peat soil is larger than other types of soil, because of the prominent effect of creep to the total settlement in peat soils [7]. Razali et al. [13] showed that peat soils are more compressible compared with dry sand under similar loading conditions on the surface. Peat soils are considered one of the most problematic soil if utilised as subgrade [6;15].

Peatlands in Indonesia covers a vast area of around 20.2 million hectares in total. It spreads in Sumatra, Kalimantan, and Papua Islands with varying depth [11]. Papua has the largest peatland though mostly deposited on the surface. On the contrary, Kalimantan has the smallest coverage area but deposited relatively deep to very deep. The majority of peatlands in Sumatra are located in Riau Province and in Kalimantan located in Central Kalimantan Province. These two provinces have 19.4% and 14.9% respectively of the total area of peatlands in Indonesia.

Peat soils are known as a type of soil that have very high void ratio, very high moisture content, very low bearing capacity, very high compression, excess settlement in the long term, including a primary consolidation, secondary compression, dan tertiary compression [12;15]. In the cohesive soil, primary consolidation is the largest contributor of the total settlement, whereas in organic soil such as peat, the largest contributor affecting total settlement is the secondary consolidation. The effect of secondary compression is quite significant for organic soils and may constitutes for more than 50% of the total settlement but still relatively small compared with its effect to inorganic soils [3]. The time required for primary consolidation is characterized by the length of time needed for the excess pore water pressure equalizes to zero, while the secondary compression stages still occur as indicated by the linear line in consolidation curve. Tertiary compression follows after secondary compression is finished. Significant secondary compression was obtained under pressure increments [10]. Duraisamy et al. [4] stated the value of compression index (C_c) of Rowe cell consolidation test for fibrous peat is in the range from 1.878 to 3.627 under consolidation pressure of 40-320 kPa. The value of compression index (C_c) obtained from oedometer test for fibrous peat is 1.453 to 3.211. To predict the settlement process in the subsoil under an embankment, it is necessary to evaluate the consolidation parameters, which are usually obtained from oedometer test. Index properties and consolidation tests of Bagansiapiapi-Riau peat is conducted to study its compressive behaviour and small-scale embankment model test were conducted in order to investigate how to reduce peat compressibility.

EXPERIMENT METHODS

Properties Test

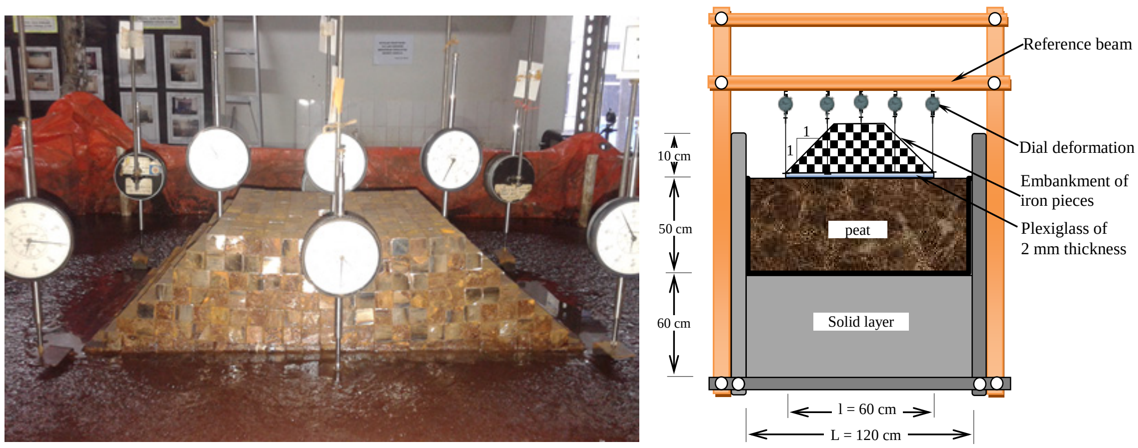
The peat soils used in this study were taken from Bagansiapiapi-Riau, Indonesia. These samples were tested to determine its physical properties such as moisture content, organic content, fiber content, and ash content. Soil with organic content above 75% classifies as peat [4] and if its fiber content above 20%, it classifies as fibrous peat. The peat sample was tested for its physical and mechanical properties. In order to test physical properties of the peat, various parameters were investigated, i.e. moisture content, density, specific gravity, ash content, organic content, and fiber content. Meanwhile to test the mechanical properties of the peat, direct shear and consolidation tests were conducted.

Consolidation Test

Compressibility of peat can be investigated from consolidated test. One-dimensional consolidation was performed using single load increment, multiple increment, and loading-unloading. Single load increment with a pressure of 25 kPa continuously applied to obtain a limit of primary and secondary consolidation and tertiary compression. Multiple increment varied according to the load duration of each load stage 24 hours and a week, while the loading-unloading is conducted by increasing the load for 24 hours, followed by unloading stage then reloading for 3 cycles.

Small-scale Model of Embankment Test

Peat soil was sieved with 1 cm × 1 cm mesh. Initial moisture content of peat soil in air dry conditions was measured for mixing and compaction process in the sample box. The mixture of peat soil sample prepared with water content similar with its natural moisture content to allow homogeneous mixing of samples. Peat sample was then compacted every 10 cm in thickness with target density similar to its in-situ density.



(a) (b)

Figure 1: The compression test with embankment in the laboratory
(a) photo of test set up; (b) test set up

Small-scale test performed in laboratory with model as shown in Figure 1a. The test box has 1.2 m × 1.2 m × 1.2 m in size. Peat soil was placed for 50 cm above the 60 cm solid layer. To obtain the optimum preloading pressure, the embankment was applying pressure by using pieces of iron bars sized 1.9 cm × 1.9 cm with the length of 4 cm. The total height of the embankment pile will be around 19 cm in height. Iron bars placed on the surface of the peat layer as thick as 3.8 cm per day. Displacement gauges were assembled in a particular distance to measure the settlement due to embankment loading. Cross section of iron bars arranged in a trapezoid shape on top of the peat sample layered by thin layer of 60 cm × 28 cm plexiglass as shown in Figure 1b. The settlement was measured in various time span within 24 during loading that continued up to 5 days. The load applied on the fifth day was left until the seventh day and then unloaded. This test gathered information on relationship between settlement duration and the load of the embankment.

EXPERIMENT RESULTS

Properties of Soil Sample

The test results on the physical and mechanical properties of Bagansiapiapi peat can be seen in Table 1. Based on the organic content, fiber content, and ash content, the soil classified as fibrous peat with low ash content.

Table 1: Properties of peat sample

No	Testing types	Results	Unit
1	Specific gravity, G_s	1.34	-
2	Ash content, A_c	1	%
3	Organic content, O_c	99	%
4	Fiber content, F_c	35	%
5	Natural moisture content, w_n	971	%
6	Density, γ_b	10.75	kN/m^3
7	Cohesion, c	2.8	kPa
8	Angle of internal friction, φ	33	^{o}
9	Initial void ratio, e	11	-

Peat Compressibility during Consolidation Test

The cconsolidation test on peat samples were conducted using a constant pressure of 25 kPa for 34 days (Figure 2). This test is necessary to determine the limit of primary and secondary consolidation and tertiary compression. The test results showed that the peat soil finished its primary cconsolidation rapidly in about 5 minutes. Compressibility of the peat soil is dominated by secondary consolidation that occurred for about 253 hours, and soon followed by tertiary compression.

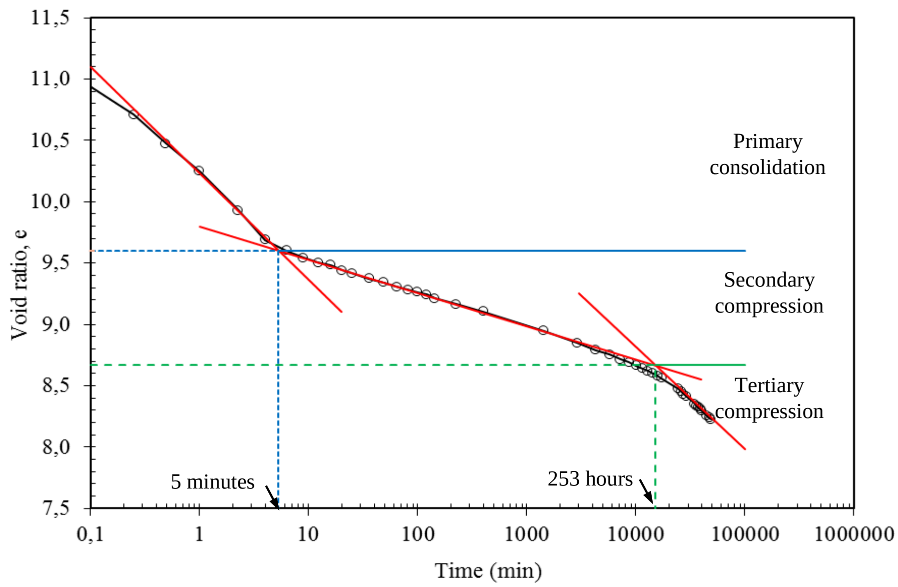


Figure 2: Compression of peat on the pressure of 25 kPa

Consolidation test results with load increment duration for 24 h and a week, as well as its load-unloading method can be seen in Figure 3. The load increment duration for 24 h produced compression curves that are smaller than other results, however compression of peat still occurs after 24 h. Compressibility of peat with the load increment duration of a week is larger than the one for 24 h. This means that the compression of peat can still occur due to secondary consolidation. In addition to consolidation test with load increment duration of 24 h, this study also conducted consolidation test with the loading-unloading method. The increase of loading cycles can reduce the compression of peat soil. Consolidation test with loading-unloading method produces compressibility of the peat equal to those load increased for a week. However, duration required for the loading-unloading system is faster than the load increment duration of a week. Thus more effective in accelerating compression in a short period of time.

Effect of loading system on peat compression

Compression of peat during loading-unloading method is generally larger than load increment duration for 24 h and it is faster than the load increment duration for a week. As shown in Figure 3, compression of peat by the method of loading-unloading resulted to larger settlement and faster process compared with other methods. Compressive behaviour of peat on loading-unloading method is similar to the load increment duration of a week, but the index compression in the loading-unloading method is smaller as incremental loading cycles. Table 2 showed that index compression on the loading-unloading method getting smaller as compared to other methods. Unlike index recompression, the load increment duration of a week gave smaller value compared to other methods. The coefficient of consolidation versus vertical stress curves is shown in Figure 4. The loading-unloading method showed decrease of coefficient of consolidation on each increment. It can be interpreted that the peat compressibility can reach maximum state by loading-unloading method.

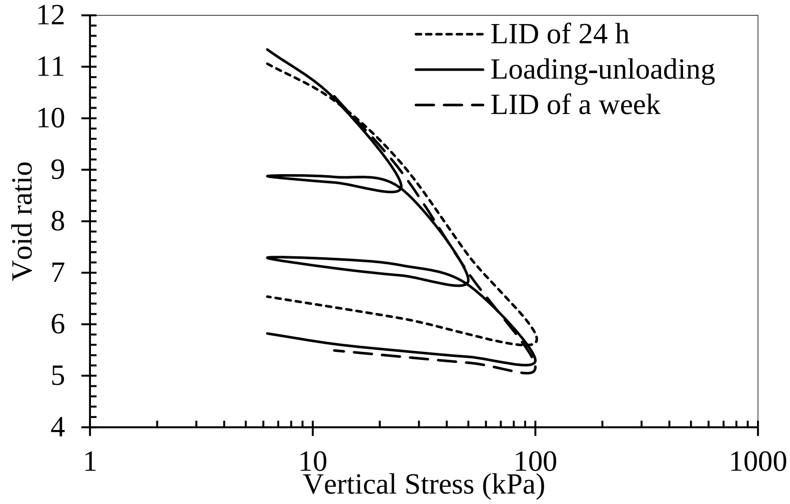


Figure 3: Relationship between load duration on void ratio vs. log vertical stress plot

Table 2 : Compression and recompression index of peat from consolidation test

Parameters	Load increment duration (LID) of 24 h	Load increment duration (LID) of a week	Loading-unloading method
C_c	5,792	6,299	5,611
C_r	0,745	0,355	0,433

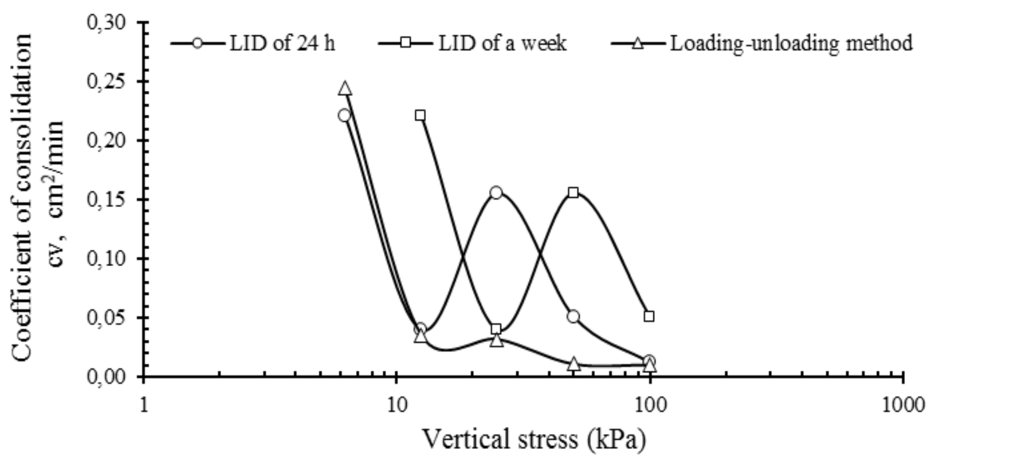


Figure 4: Relationship between load duration on coefficient of consolidation vs. log vertical stress plot

Effect of drainage path thickness on consolidation time

The consolidation time in the peat layers can be analyzed by the coefficient of consolidation, time factor, degree of consolidation, and drainage path length of peat layer. The rate of consolidation depends on drainage path length and coefficient of consolidation. Relationship of consolidation time with the drainage path thickness can be computed by following equation:

$$t = \frac{T_v.H^2}{C_v} \quad (1)$$

where t: consolidation time, T_v: time factor, H: drainage path length, and C_v: coefficient of consolidation. If using value of the average coefficient of consolidation, C_v = 0.096 cm^2/min, then the peat layer as thick as 50 cm with one-way drainage consolidation will take 15 days to be 90% consolidated. Consolidation time of the peat layer of various thicknesses on the degree of consolidation of 50% to 90% can be seen in Figure 5. The drainage path length of peat layer affects the rate of consolidation and the consolidation time will take longer on the thicker peat.

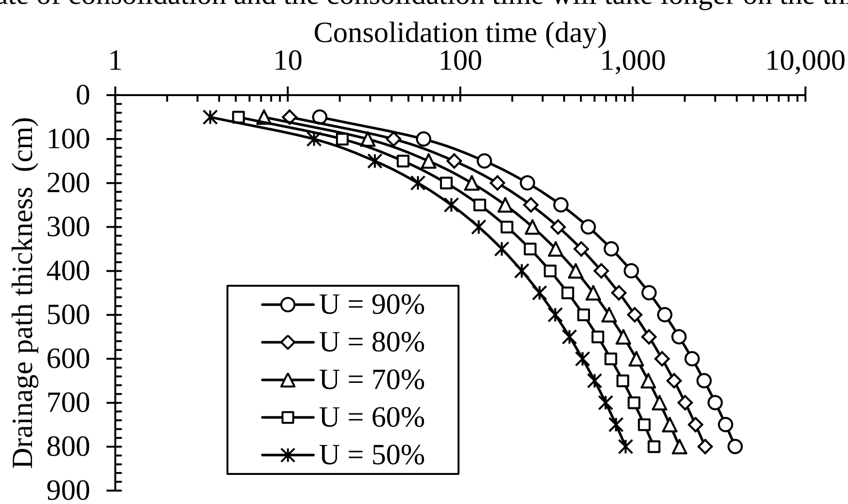


Figure 5: Rate of consolidation on peat layer

The Settlement of Peat due to Embankment

Settlement of peat can be identified by applying embankment on the surface of the peat deposit. Small-scale model was applied pressure by incremental loading. Each load increment that was portrayed by the embankment is proportional to the pressure of 2.72 kPa. The deflection that occurred at specified point in the cross direction of the embankment can be seen in Figure 6. Deflection curved towards the center of embankment. Deflection occurred indicate peat compression due to embankment. Additional load of embankment results small compression of the peat.

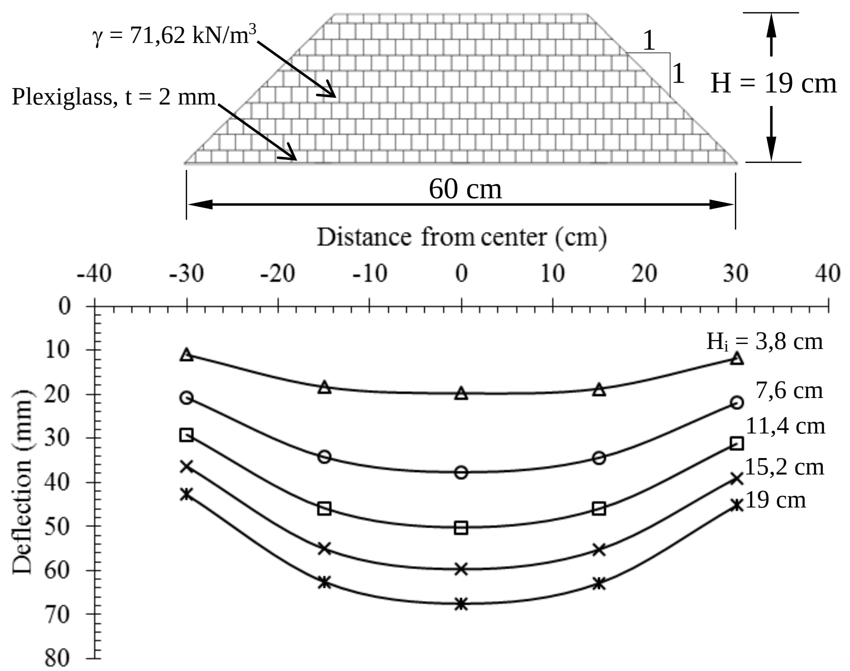


Figure 6: Deflection at the cross direction of embankment

Compressibility of peat due to embankment showed in the relationship between time and settlement in center of embankment (Figure 7). Compression of peat decreased due to the load of embankment. The compression seems small at the last loading series of around 13.61 kPa. Improvement of compressibility is shown in relationship between time and settlement (Figure 8). The addition of incremental load in a relatively long time can improve the compressibility of the peat soil. Load increment duration of 24 h seemed to minimize compression of peat. The embankment loading can result to consolidation on the peat so that the bearing capacity will increase.

The field settlement data are used to verify the applicability of the observational methods, namely the hyperbolic and the Asaoka method. Tan et al. [14] and Chung et al. [2] proposed a hyperbolic relationship between field settlement (s) and consolidation time (t). The hyperbolic curve is expressed as Equation 2. Hence the final settlement (s_f) is defined as Equation 3. According to Asaoka [1], settlement at time (s) can be expressed as Equation 4.

$$s = \frac{t}{\alpha + \beta t} \quad \text{or} \quad t = \frac{\alpha s}{1 - \beta s} \tag{2}$$

$$s_f = \frac{1}{\beta} \quad (3)$$

where α and β are the intercept and the slope of initial liner line respectively, in relationship between the ratio of *t/s* on the ordinate and time *t* on the abscissa [5].

$$s_n = \beta_o + \beta_1 s_{n-1} \quad (4)$$

where, s_n dan s_{n-1} is the settlement at time *n* and *n*-1; β_o and β_1 are unknown parameters. In a time-settlement relationship, which is a linear equation, where β_o is an intercept on the vertical axis and β_1 is its gradient [5]. When the condition is stable, the final settlement s_f can be obtained by Equation 5. The final settlement is the intersection of relationship line between s_n and s_{n-1} with 45^o line in the $s_n - s_{n-1}$ plot [8].

$$s_f = \frac{\beta_o}{1-\beta_1} \quad (5)$$

The settlement *s(t)* at time *t* can be calculated as follows:

$$s_t = s_f (1-\exp((\ln\frac{\beta_1}{\Delta t})t)) \text{ or } t = \frac{\ln(1-(s_t / s_f))}{\ln(\beta_1 / \Delta t)} \quad (6)$$

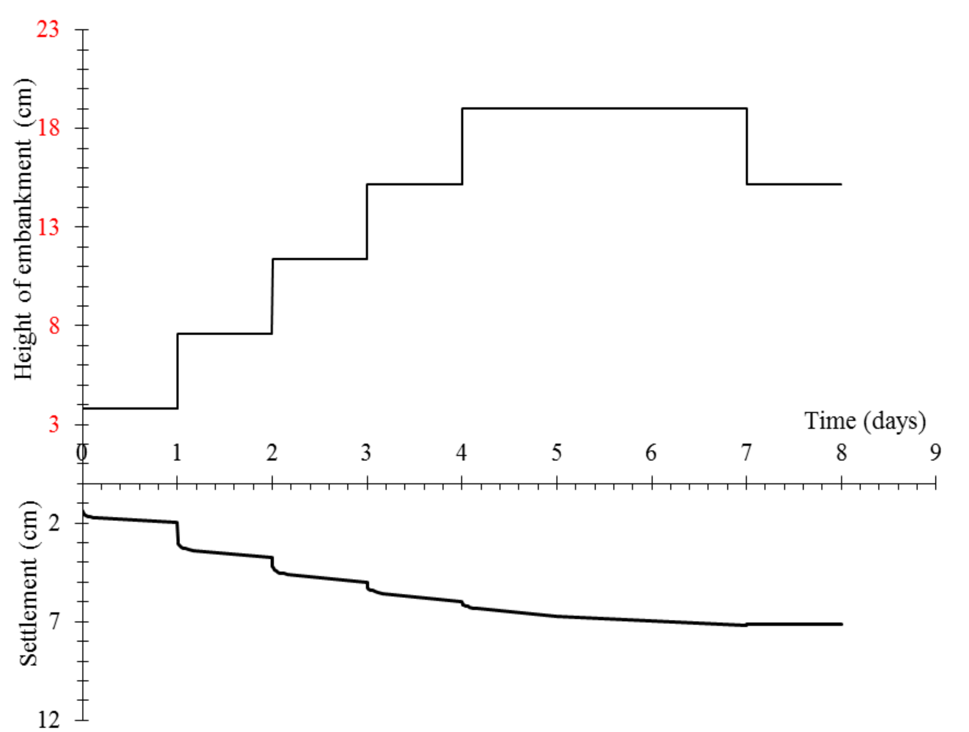


Figure 7: Settlement at center of embankment

Based on the observation data, the parameter α and β can be obtained according to hyperbolic method, and calculation results are 0,383 and 0,0782 respectively. Parameter β_o and β_1 can also be obtained based on Asaoka's method. The calculation of the parameter β_o and β_1 result are

2,3128 and 0,7294 respectively. These parameters are used to determine final settlement. The potential settlement can be calculated from Equation 2 (hyperbolic method) and Equation 6 (Asaoka's method). Comparison was made among each settlement that was estimated by the observational methods, as shown in Figure 8. It can be seen that the values from hyperbolic method are about 1,08 times higher than the values Asaoka's method. Due to the limitations in data measurement, it is likely that the estimated values from hyperbolic method are larger than those obtained from the Asaoka's method. The predicted settlement curves obtained from Asaoka's method are in general agreement with the measured curves.

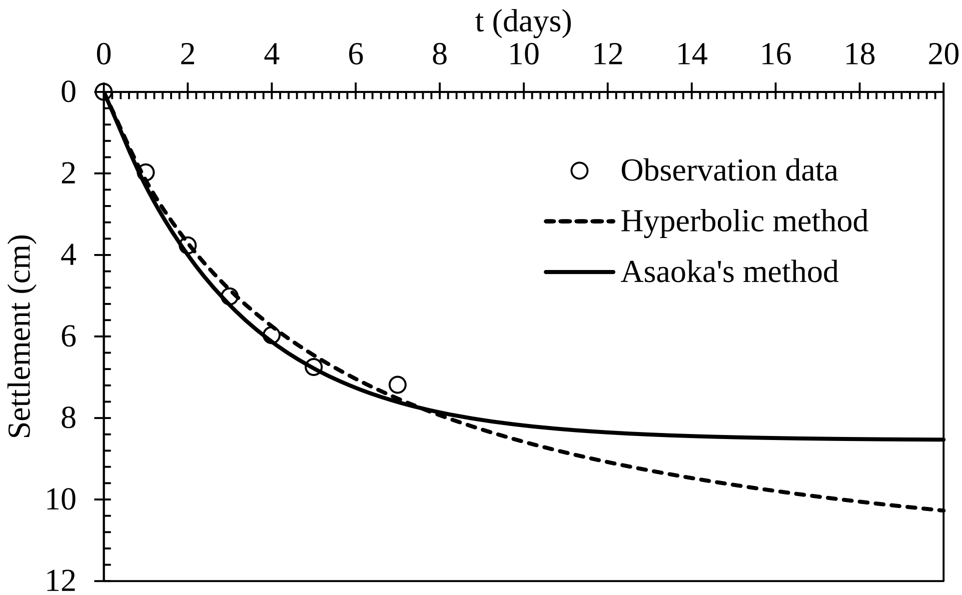


Figure 8: Result comparison of Hyperbolic and Asaoka's methods with the observation data

CONCLUSION

The fibrous peats with low ash content have very high compressive behaviour and dominated by secondary consolidation. Compression of Bangansiapiapi peat is still high after 24 hours with gradual increment. This behavior is seen in the difference of compression index for one-week gradual loading that is higher compare with the compression index for 24 hours. The loading-unloading method can accelerates the compression of peat and further reduced the compressibility. Compression on samples tested by the loading-unloading method is similar to the incremental loading method within a week, but with much faster rate. The loading-unloading method is very favorable for peat soils that have a high compressibility in a long period.

The embankment load can reduce the compressibility of peat. This method can improve the compressive behaviour of peat soils. The preloading with the loading-unloading method on peat soil considered capable to speed up the compressibility of peat soils.

Comparison was made between each of the settlement obtained by the observational method. It was found that the values obtained from hyperbolic method are about 1,08 times higher than the values Asaoka's method. The predicted settlement curves obtained from Asaoka's method are in general agreement measured curves.

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