In-Situ Consolidation Analysis By Asaoka And Hyperbola Methods

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Abstract: This research aims to consolidation settlement evolution of eight-story building by applying surcharge preloading, constructed for commercial purposes at Philadelphia International Airport in Pennsylvania where preloading was used to escalate the settlement. The consolidation process was carried out by installing two settlement sensors and six settlement plates in the site area. In-situ values are recorded at all the devices throughout the surcharge filled area with an interval of one month for a year. In this study, Asaoka and Hyperbola methods were compared for monitoring the evolution of consolidation to conclude their similarities and differences, and their precision of predictions compared to actual observations. It has been observed that settlement data beyond a 60% consolidation stage are needed to make a precise prediction of final settlements. It was observed that both methods are good enough to predict final settlement and consolidation coefficients.

Index terms: Asaoka method, Consolidation, Hyperbola method, Settlement, and Surcharge.

1. Introduction

To construct a shallow foundation in fine-grained soils, it is needed to calculate settlement of Consolidation, is usually a controlling design issue when constructing a shallow foundation at a site, it consists of saturated and smooth soils. The settlement due to the loads from the foundation and supporting structure includes a small amount of elastic compression and secondary settlement along with a larger amount of primary settlement, where the pore water is "squeezed out" from the soil. Generally, although consolidation parameters are obtained from in-situ and laboratory tests. The settlement and consolidation time is complicated to precisely predict [1-8]. Owing to such imprecision, it is typical practice to be correct the settlement vales at the design stage based on obtained and observed values from the site Several methods that are broadly used in exercise are known to offer reasonable estimations of final settlement and coefficient of consolidation, such as Asaoka method (1978), Hyperbolic method (Tan et al. 1991; Tan 1995), and other methods like Tan et al. (1996) compared the Asaoka and Hyperbola methods for monitoring the evolution of consolidation to conclude their similarities and differences, and their precision of predictions compared to actual observations [9-14]. It has been observed that both methods gave good agreement with predictions. Chung et al. (2009) predicted the performance of wick drains by hyperbola method which is developed based on Barron's solution and validated by using three documented case studies and found that this method is suitable within the degrees of consolidation of 60–90% [15-18]

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2. Objective

- The ultimate goal of the current study is only, to compare the in-situ Consolidation Analysis by Asaoka and Hyperbola methods.

3. Methodology

3.1. Geotechnical data

The subsurface circumstances at the site have been explored through numerous test borings, cone penetration investigation, and comprehensive laboratory testing [19]. An in-situ instrumentation program was conducted to closely monitoring the settlements and excess pore pressures during preloading and unloading. The subsurface soil profile (from top to bottom) comprises of (1) existing fill consists sixty sand(loose to medium-dense) with a thickness of 1 meter,(2) recent Delaware River deposit (very loose to loose silty sand) and sandy silt with fly ash with a thickness of 2.5 meter, (3) Delaware River siltvery soft to soft organic) with a thickness varies from 2.3 to 3.8 meter across the building pad and (4) sandy gravel and gravelly sand (medium-dense to dense) extended about 27 m below the base of the silt to the top of mica schist bedrock. A well-compacted surcharge fill material was placed on these four subsurface soils for the preloading program. Evidently, any significant load from the structure would result in the organic silt layer an excessive consolidation settlement. However, to eradicate this settlement ahead of the construction, a preloading plan was accomplished [20]. As such, an earth embankment was placed on the building pad area to act as a surcharge over the underlying organic silt. For this reason, addressing the shallow foundations became practicable to support the hotel building.

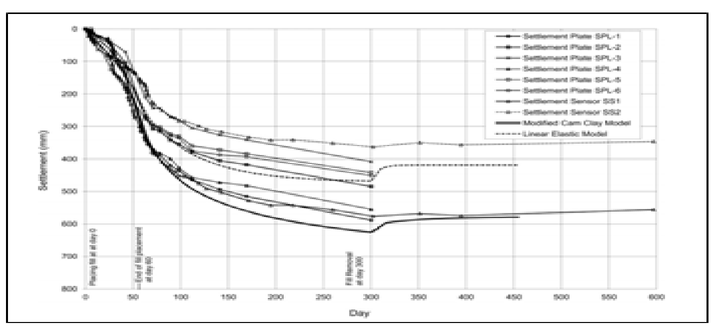

Fig. 1. *Cumulative settlement throughout the surcharge program (With permission from ASCE).*

Generally, Terzaghi's 1-D consolidation theory (Terzaghi, 1925) has been extensively used to calculate Settlements. Although this theory is inefficient due to the improbability of the coefficient (Asaoka, 1978). Based on observational data, several methods have also been proposed to predict the final Settlements. For example, Asaoka proposed a new method in 1978 and the hyperbolic method proposed by Tan et al., in 1991 and in the year 2000, Xu and Xu proposed a new method and named it as parabola method and field tests by Bergado et al., in 1991. However, due to their simplicity, the Asaoka method and hyperbolic method are extensively used (Anderson et al., 1994; Tan, 1994, 1995, 1996).In this study, a measured settlement with respect to time data as shown in Fig. 1, has been used for calculating the final settlements and coefficient of consolidation (by using Asaoka and Hyperbola methods) across the site with respect to the locations of eight settlement devices.

3.2. Asaoka method

In 1978, a new method was introduced by Asaoka for prediction of final settlement, which is based on "observational procedure". The final settlement can be obtained by plotting Si values on the y-axis and Si-1 values on the x-axis. Where Si is the settlements at the time I and Si-1 are the settlements at time i-1. In this method, the intersection of the relationship line between Si and Si-1 with 450line in the Si versus Si-1 plot represents the final settlement as shown in Figs. 2,4,6,8,10,12,14 and 16. The consolidation coefficient can be calculated using eq. (1).

$$C_v = -\frac{4H^2}{\pi^2 \Delta t} \ln \beta \qquad \text{eq. (1)}$$

3.3. Hyperbola method

Tan et al. (1991)introduced a hyperbolic relationship between recorded settlement (s) and consolidation time (t), which includes two linear segments. Hence, the final settlement was defined as eq. (2).

$$S = \frac{t}{\alpha + \beta t} \text{ (or) } \frac{t}{s} = \alpha + \beta t$$

$$\lim_{t\to\infty} s = \lim_{t\to\infty} \frac{1}{\frac{\alpha}{t} + \beta} = S_f = \frac{1}{\beta} \quad \text{(or)} = \frac{0.859}{\beta} \qquad \text{eq. (2)}$$

In 1987 Sridharan et al., recommended the rectangular hyperbola method, which is based on Terzaghi's U-Tv relationship equation, is a rectangular hyperbola over an adequate wide range of Tv and the coefficient of consolidation can be calculated by using the eq. (3).

$$C_V = \frac{0.24mH^2}{c} \qquad \text{eq. (3)}$$

Where c, is the intercept and m is the slope of the initial liner line respectively in the t/s v/s t plot as shown in Figs. 3,5,7,9,11,13,15 and 17.

4. Results and discussions

The parameters which are used to predict the final settlement and consolidation coefficient, like thickness of compressible layer(H), time interval (Δt), slope of the linear line (β) for Asaoka method and slope of linear line (m), intercept (c) for hyperbola method are tabulated in tabulated table1. It has been observed that the total amount of measured settlement was ranges from361 to 588mm as shown in Fig. 1. This indicates the settlement rate is varying across the site are due to thickness variation of the compressible layer (organic silt) ranges from 2.3 to 3.8m. The predicted consolidation parameters by Asaoka and hyperbola methods for all the settlement devices are tabulated in table2. The final settlement by the Asaoka method ranges from 375 to 615mm whereas the final settlement by Hyperbola method ranges from 373mm to 613mm. The average predicted ultimate settlement ranges from 374mm to 614mm as shown in Fig.19. It was found that the coefficient of consolidation from the Asaoka method ranges from 2.33 m2/yr to 6.82 m2/yrwhereas, from the Hyperbola method, it ranges from 1.74 m2/ yr to 5.29 m2/ yr. The average coefficient of consolidation is ranging from 2.03 m2/yr to 6.05 m2/yr as shown in Fig 20. Finally, the authors conclude that the measured field settlements and the predicted final settlements by both Asaoka and Hyperbola methods slightly differ and are seemed to follow similar settlements rates as shown in Fig.18. It has been observed that the final settlement by the Asaoka method predicts the 1.013 times the Hyperbola method. The agreements between measured and predicted final settlements are well within an error of 2.5%. Certainly, it is quite complicated to sufficiently fund a linear line and time interval in the Asaoka plot, which should depend on individual results.

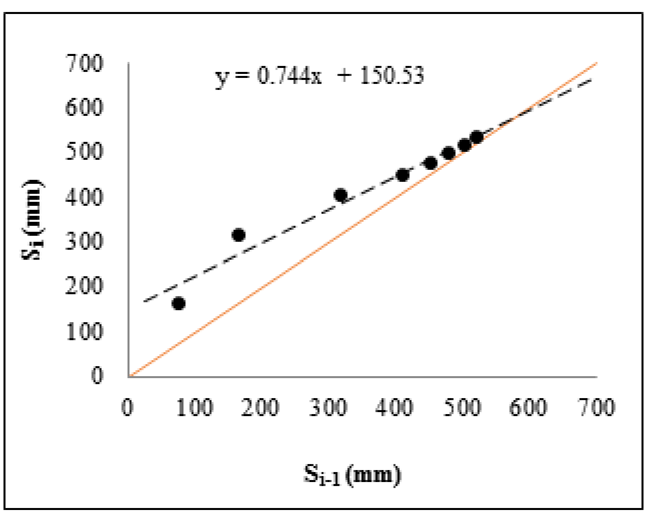

Fig. 2. *Si versus Si-1 plot for settlement sensor-1 (ss1)*

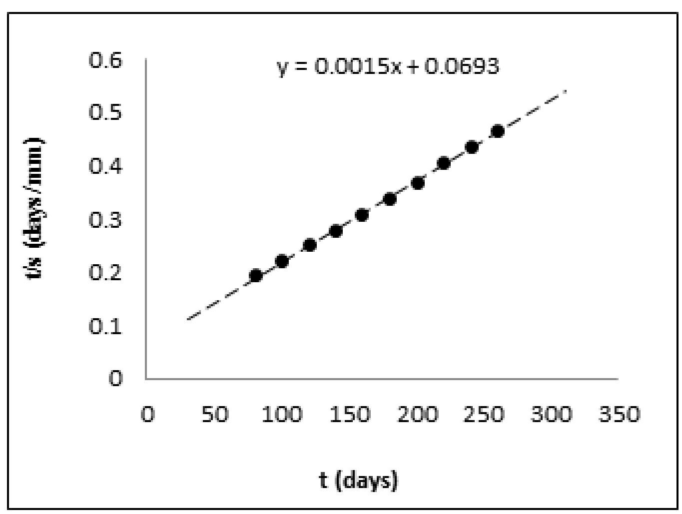

Fig. 3. *t/s versus t plot for settlement sensor-1(ss1)*

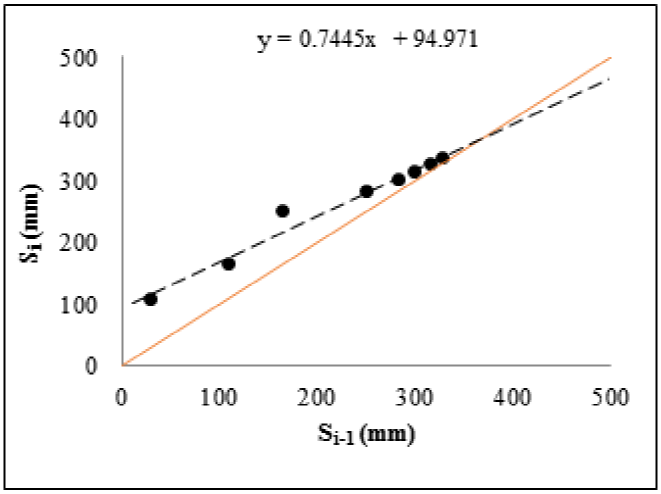

Fig. 4. *Si versus Si-1 plot for settlement sensor-2 (ss2)*

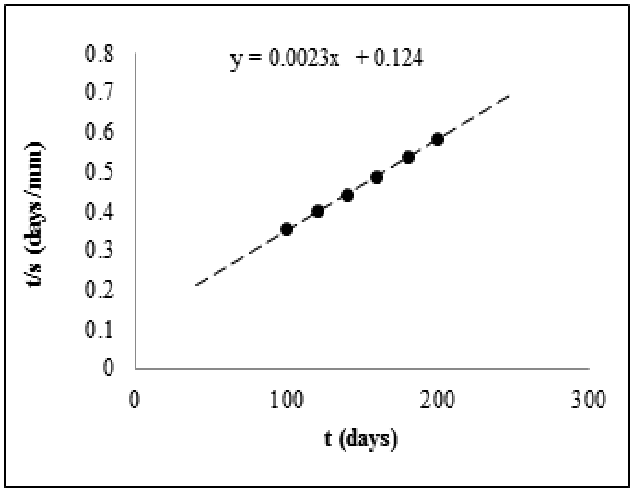

Fig. 5. *t/s versus t plot for settlementsensor-2 (ss2)*

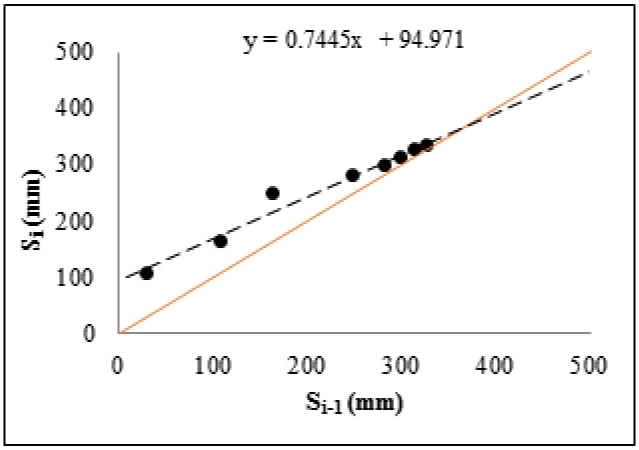

Fig. 6. *Si versus Si-1 plot for settlement plate-1(spl1)*

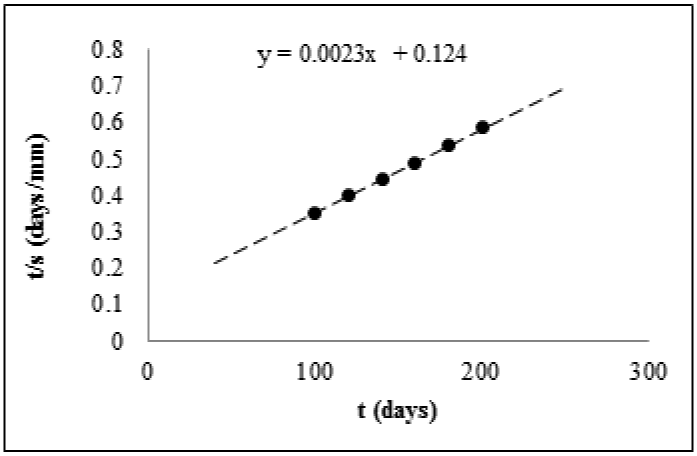

Fig.7. *t/s versus t plot for settlement plate-1(spl1)*

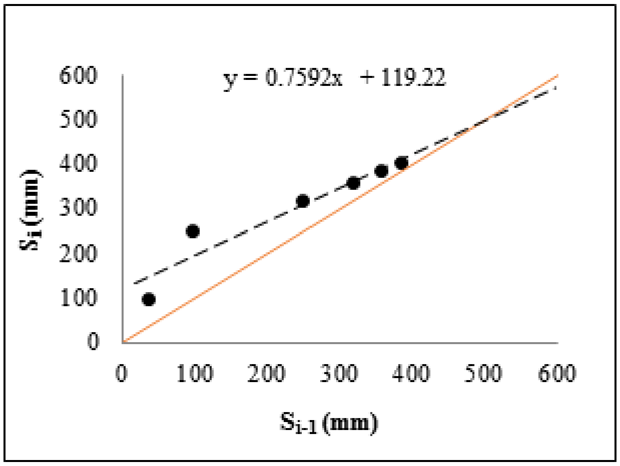

Fig. 8. *Si versus Si-1 plot for settlement plate-2(spl2)*

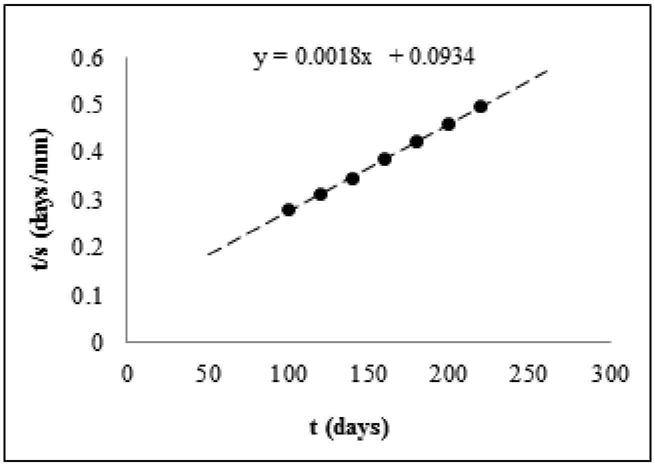

Fig. 9. *t/s versus t plot for settlement plate-2(spl2)*

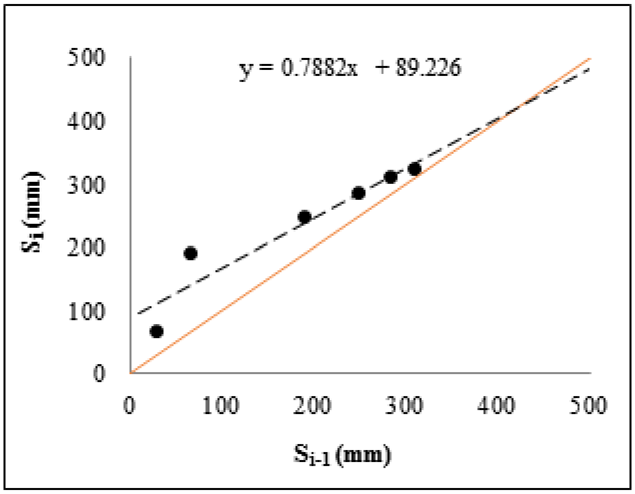

Fig. 10. *Si versus Si-1 plot for settlement plate-3(spl3)*

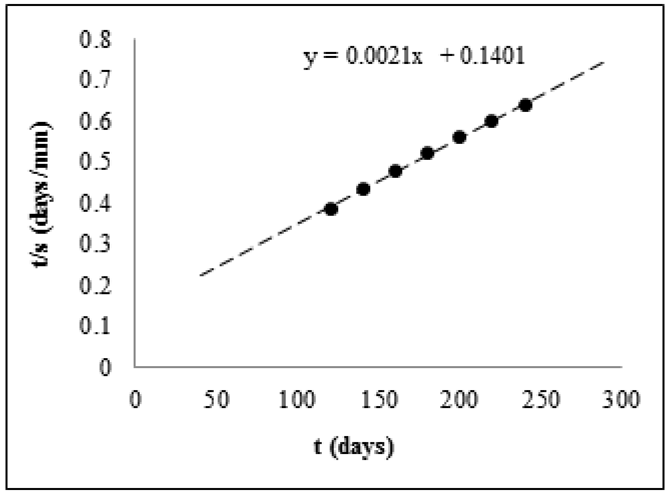

Fig. 11. *t/s versus t plot for settlement plate-3(spl3)*

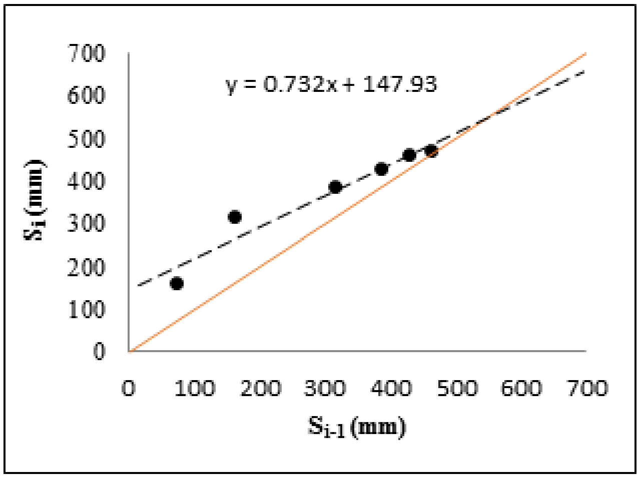

Fig. 12. *Si versus Si-1 plot for settlement plate-4(spl4)*

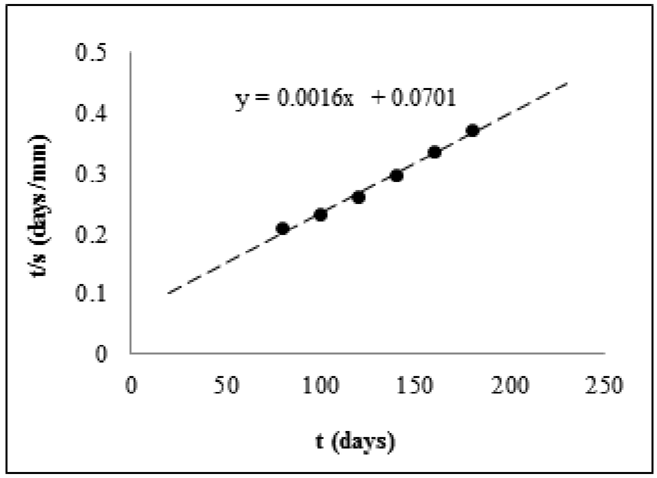

Fig. 13. *t/s versus t plot for settlement plate-4(spl4)*

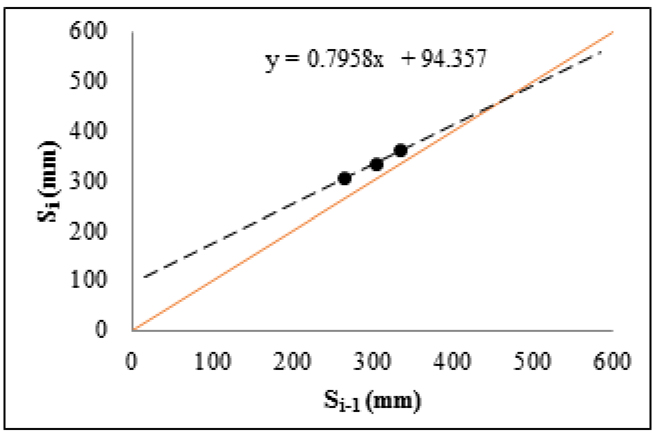

Fig. 14. *Si versus Si-1 plot for settlement plate-5(spl5)*

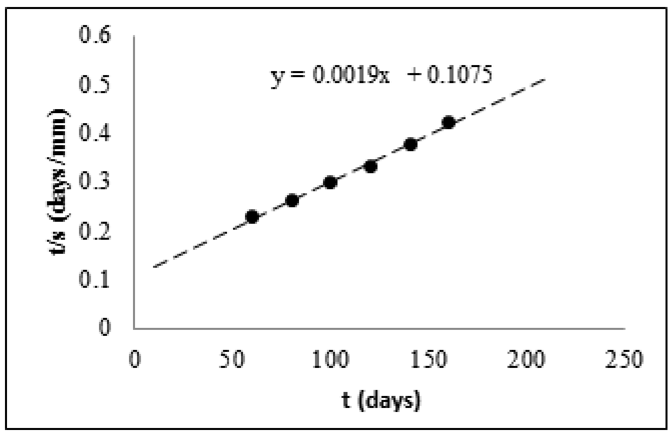

Fig. 15. *t/s versus t plot for settlement plate-5(spl5)*

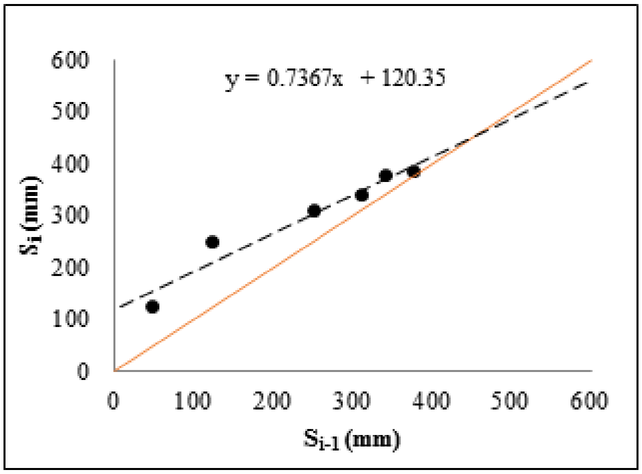

Fig. 16. *Si versus Si-1 plot for settlement plate-6(spl6)*

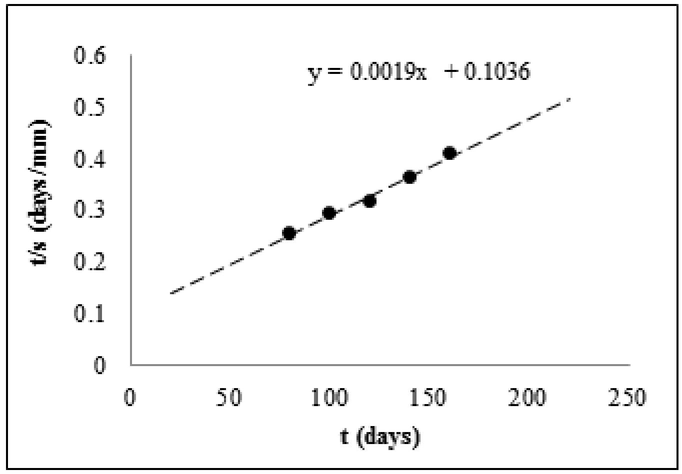

Fig. 17. *t/s versus t plot for settlement plate-6(spl6)*

Notation

H = thickness of the compressible soil layer.
Δt = time interval.
Β = slope of a straight line on the curve in the Si versus Si-1 plot.
M = slope of the initial linear line in the t/s versus t plot.
C = interception the t/s versus t plot.
Cv = coefficient of consolidation
Sf = final settlement

It has been observed that for both methods, more than 60% consolidation stage of settlement data is required to precisely predict the final settlements and consolidation coefficients. The consolidation coefficient results from the Asaoka method are slightly larger compared to the results from the Hyperbola method. It was found that the hyperbola method underestimating the consolidation coefficients by 1.26 times the Asaoka method. Although both Ashoka and Hyperbola, methods gave very good predictions of final settlement and consolidation coefficients. It can be concluded that both methods can be applied effectively for estimating consolidation settlement.

Table 1. *Description of H, Δt, β, m and c values for methods of Asaoka and Hyperbola.*

Settlement device	H (m)	ASAOKA METHOD		HYPERBOLA METHOD	
		Δt (days)	β	m	c
ss1	2.6	20	0.744	0.0015	0.0693
ss2	3.4	20	0.7445	0.0023	0.124
spl1	3.8	20	0.7746	0.0014	0.0837
spl2	2.4	20	0.7592	0.00174	0.0934
spl3	2.3	20	0.7882	0.0021	0.1401
spl4	2.9	20	0.732	0.00154	0.0701
spl5	2.9	20	0.7958	0.0019	0.1075
spl6	3.4	20	0.7367	0.0019	0.1036

Table 2. *Final settlement (S_f) and coefficient of consolidation (C_v) for Asaoka and Hyperbola method*

Settlement device	ASAOKA METHOD		HYPERBOLA METHOD	
	Sf (mm)	Cv (m2/yr)	Sf (mm)	Cv (m2/yr)
ss1	580	3.70	573	3.20
ss2	375	6.31	373	4.70
spl1	615	6.82	613	5.29
spl2	500	2.93	494	2.35
spl3	420	2.33	409	1.74
spl4	565	4.85	558	4.05
spl5	460	3.55	452	3.26
spl6	460	6.53	452	4.64

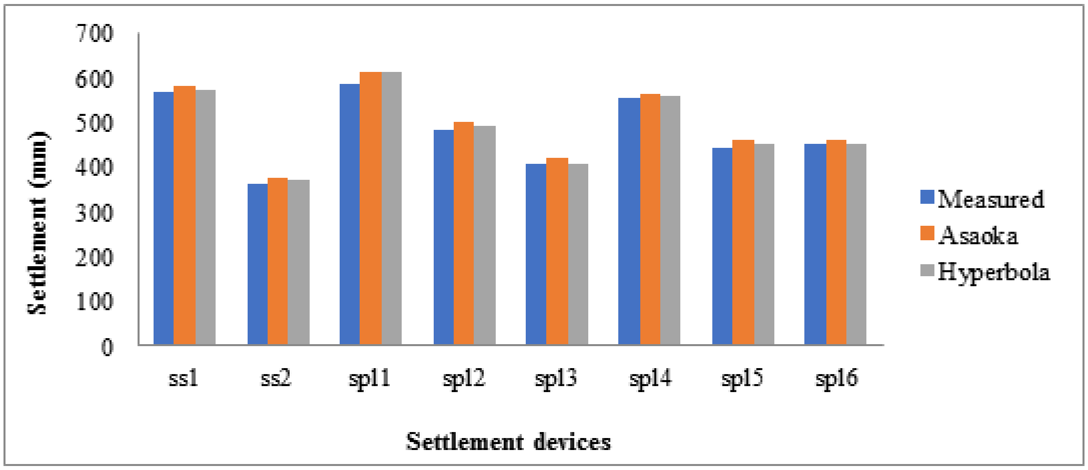

Fig. 18. *Comparison of final settlements (Sf) of Measured, Asaoka's and Hyperbola methods*

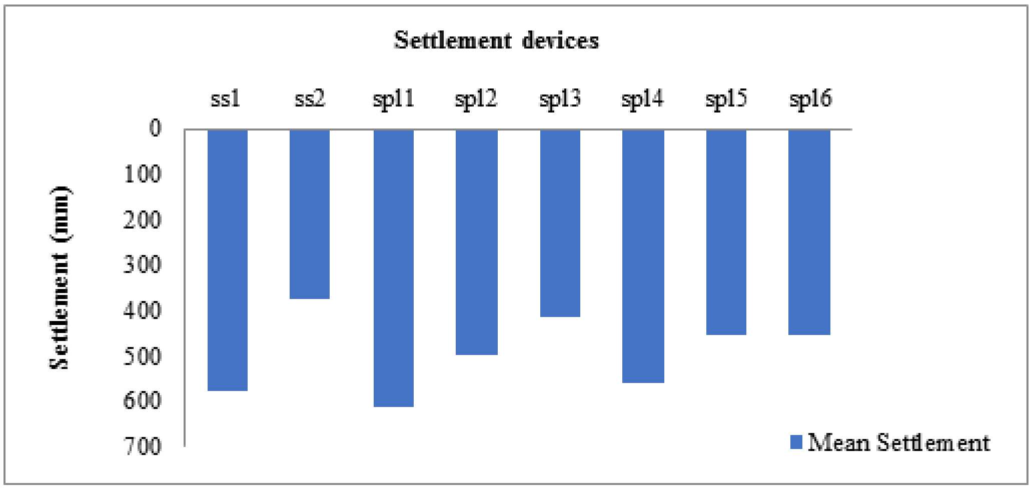

Fig. 19. *The Average final settlements from Asaokas and Hyperbola methods*

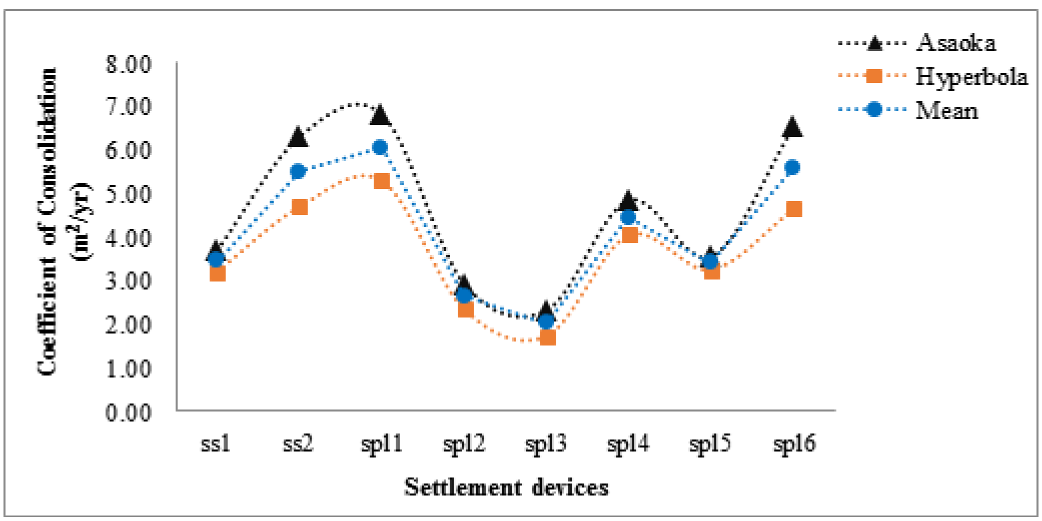

Fig. 20. *Comparison of Coefficient consolidation (Cv) from Asaokas and Hyperbola methods.*

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