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ANALYSIS OF CONSOLIDATION DEGREE USING SETTLEMENT OBSERVATION RESULTS AND ASAOKA METHOD: A CASE STUDY OF ROUTE KM 94+340 -:- KM 94 + 440 OF HANOI - HAIPHONG HIGHWAY CONSTRUCTION PROJECT

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ABSTRACT

In this paper, we used Asaoka method for determining consolidation degree of the soft ground as it is the most simple and reliable method. For this, settlement observation results collected from km 94+340÷ km 94+440 of Ha Noi – Hai Phong highway construction project were used. Validation was also done by comparing the consolidation degree determined from the Asaoka method and technical design records from the project. The results show that the consolidation degree calculated from observational data using Asaoka method is 99.81% which is larger than technical design record data (90%).

Key words: Consolidation Degree, Asaoka method, Soft Soil, Viet Nam

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1. INTRODUCTION

In the calculation of soft ground treatment using vertical drain combined with pre-loading method, the determination of time for removing loading and construction for the superstructure of the embankment is very important. Consolidation degree is one of the important geotechnical parameters used for this problem. There are several methods for evaluating consolidation degree of the soft ground using observation results namely Asaoka, Hyperbolic, and Moden etc. Each method has its advantages and disadvantages, and different accuracy. Whereas, the method for determining of consolidation degree over time using settlement observation results by Asaoka method is considered as the simplest and most reliable method.

In this study, the main objective is to apply Asaoka method for determining consolidation degree of the soft ground as it is the most simple and reliable method. For this task, settlement observatıon results collected from km 94+340÷ km 94+440 of Ha Noi – Hai Phong highway construction project were used. Validation was also done by comparing the consolidation degree determined from the Asaoka method and technical design records from the project.

2. CONSOLIDATION OF SOFT SOILS [1]

Soil is constituted from soil particles and pore system between soil particles. Pore system can be fully filled by water (saturated soil), a small amount of water or without water. In the cases of containing a small amount of water or without water, when the soil is compressed, first soil skeleton is deformed immediately, then the link between soil particles is destroyed and soil particles move closely together, results in gradual reducing the porosity and make the soil denser. For the saturated soil, when soil compressed, the behavior is almost same as that of above-mentioned. However, because the pore is fully filled by water, the soil particles move closer together and water in the pore is dissipated. The compressibility of saturated soil associated with pore water dissipation is called as consolidation. The consolidation process can be divided into two stages such as (1) Primary consolidation: is the process that water in pore dissipates, the pore becomes smaller, thus soil is denser and (2) Secondary consolidation: is the process that pore water has fully dissipated, however, soil particles continue moving and sliding over each other to a stable position.

Let consolidation degree Ut is the ratio between settlement at time t and stable settlement (final settlement). Following equation is often used to determine the consolidation degree of soft soils:

$$U_t = \frac{S_t}{S_\infty} \quad (1)$$

where St is settlement at time t and S∞ is the final settlement (primary settlement) is the maximum settlement under constant loading.

3. SETTLEMENT OBSERVATION [2]

For the soft soil treatment using vertical drain combined with pre-loading method, the actual settlement on site at time t is determined using settlement plate. Settlement plate has a size of 800 mm × 800 mm, 30 mm in the thickness, is embedded tightly to measuring rod, which made from steel with a diameter smaller than that of casing tube (not allow soil contact with measuring rod); casing tube is not attached with settlement plate. Measuring rod has 50 mm in diameter; measuring rod and casing tube are divided into segments, each segment has 0.5 to 1.0 m in length in order to join easily following filling height (Figure 1).

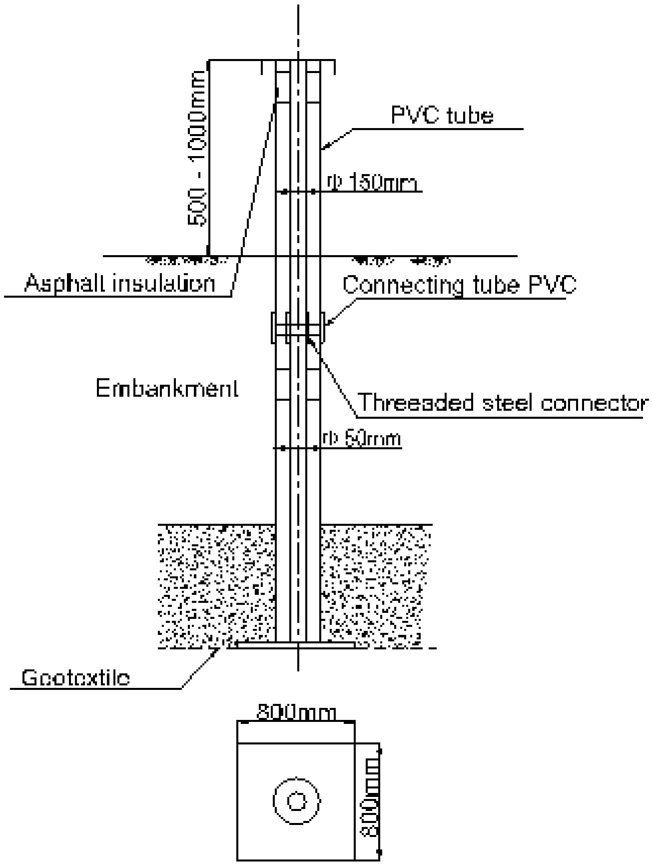


Figure 1 Constituent of settlement plate

Settlement plate is placed at starting level of filling elevation of embankment: if the sand mat exists, the settlement plate is placed on the sand mat. If there is a natural stiff layer above soft ground, the settlement plate is placed on the natural stiff layer; and if there is geotextile layer, the settlement plate is also placed on the geotextile layer. In the case of the settlement plate must be placed on the soft ground, it is needed to remove 30 cm of soft ground in the area of settlement plate, and replaced by sand, after that, placing the settlement on the sand layer. The settlement plate must be in good conditions until handover works finish.

In general, surface settlement monitoring is conducted using conventional geodesy method with the level machine and leveling pole (Figure 2). Elevation of pipe head of settlement plate is determined based on elevation measurement work, conducting technical leveling from benchmarks to settlement plate. The settlement is the difference between initial elevation and elevation at different interval time of measurements.

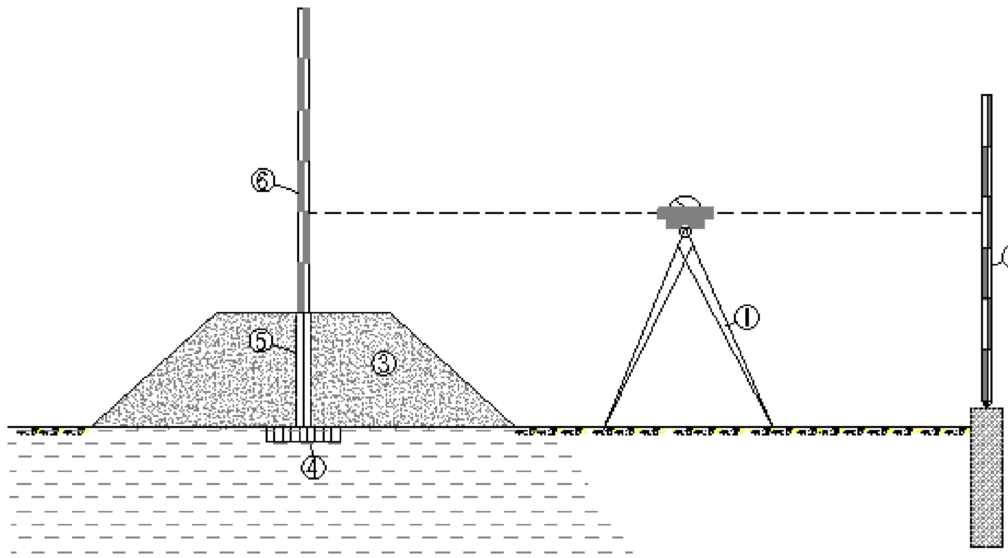


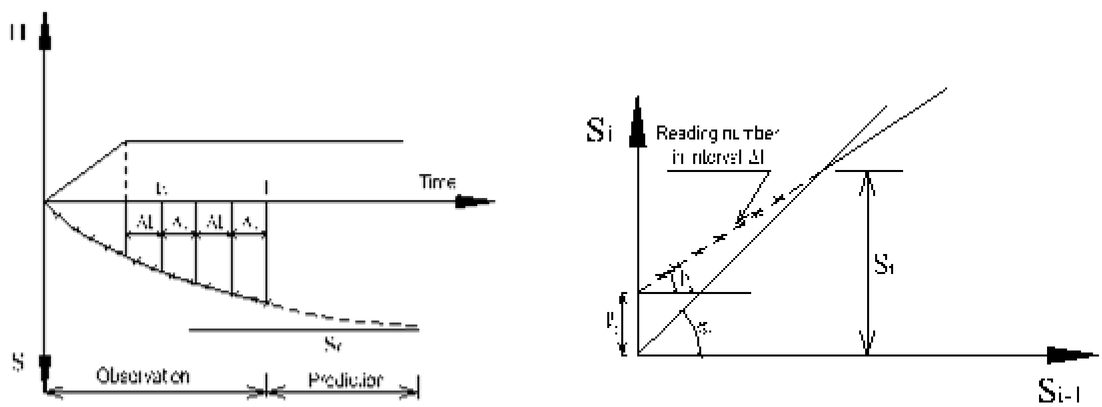
Figure 2 Surface settlement monitoring layout (Note: 1 - Level machine, 2 - Benchmark, 3 - Embankment, 4 - Settlement plate, 5 - Plastic tube, and 6 - Leveling pole) [4]

Settlement monitoring work is conducted immediately once per day after placing settlement plate during filling embankment and pre-loading process; if filling work is divided into several stages, it should be monitored daily for each stage. When there are abnormal problems of construction, it is required to implement off-cycle measurements. Adjustment of settlement data must be implemented immediately after the measurement in order to make necessary decisions regarding the construction progress and the speed of loading.

4. ASAOKA METHOD [3]

Asaoka method uses settlement observation results from filed data to determine consolidation degree and predict final settlement of soft ground using vertical drain combined with pre-loading method.

Asaoka has proved that if we divide settlement observation curve into multi-point S_i with the same interval of time when we draw the graph with horizontal axis by S_{i-1} and vertical axis by S_i, all points belong to a straight line. This is validated when loading is constant, corresponding to maximum filling load. The final settlement is the intercepting point of the lines connecting all points with the 45°-line [1].



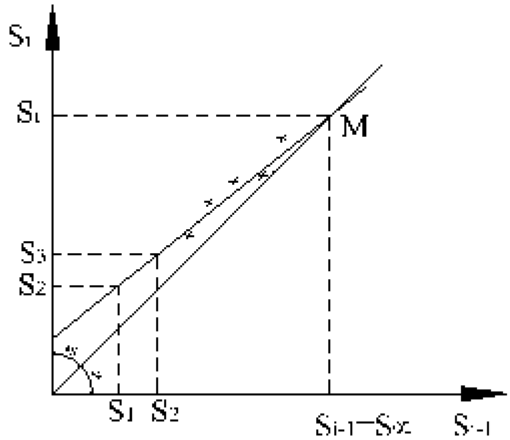


Figure 3 Settlement analysis based on Asaoka method

According to consolidation theory, for the constant loading, this relationship curve is a straight line, which helps us to calculate different consolidation parameters for actual conditions, including primary settlement (at the intercepting point of a straight line and median line). In fact, the theory of settlement is as follows:

$$S_i = S_\infty.(1 - \frac{8}{\pi^2}.e^{(-C.t)}) \quad (2)$$

Where

$$C = \frac{8.C_r}{d_e^2.F(n)} + \frac{\pi^2.C_v}{4.H^2} \quad (3)$$

where C_r is radial coefficient of consolidation, C_v is vertical coefficient of consolidation, t is time, H is permeability length, d_e is effective diameter of the drainage device ($d_e = 1.13 \times d_s$ for the square grid, d_s is the distance between two adjacent PVDs or sand drains);

$$F(n) = \frac{n^2}{n^2 - 1}.\ln(n) - \frac{3.n^2 - 1}{4.n^2} \quad (4)$$

$$n = d_s / d_w \quad (5)$$

Where d_w is equivalent diameter of drainage device.

For determined Δt, we have:

$$S_i = S_\infty.(1 - \frac{8}{\pi^2}.e^{(-C.(t+\Delta t))}) = S_\infty.(1 - e^{(-C.\Delta t)}) + e^{(-C.\Delta t)}.S_{i-1} \quad (6)$$

$$\Rightarrow S_i = \beta_o + \beta_s.S_{i-1} \quad (7)$$

The above relationship line is a straight line with a slope β_s that related to C coefficient. When the slope of this line is determined, consolidation coefficients can be determined. In addition, the settlement at time t can be calculated simply by reading the settlement at the intersection between this relationship line and the median line.

The final settlement:

$$S_{\infty} = \frac{\beta_o}{1 - \beta_s} \tag{8}$$

5. DATA USED

A Case Study of Route Km 94+340 -:- Km 94 + 440 – of Hanoi- - Haıphong Highway Construction Project. The road is designed using highway standard type A with a design speed of 120 km/h [8]. The average road width is 100 m (including 06 lanes with each lane has 3.75 m in width, 02 emergency lanes, median at the center, tree line at two sides, frontage roads at the necessary section). Geotechnical profile of the studied route is shown in Figure 4 which includes layer 1 – filling material: sand for filling sub-base, 0.4 m in thickness, there is no experiment results of soil sample, layer 2 - blue-gray clay, black-gray containing organic matter, plastic liquid-liquid state, clamped layer - sand in plastic, porous, and saturated state, 0.9 m in thickness, layer 3 – blue-gray clay in the soft plastic-liquid plastic state, with a thickness of 7.9–9.7 m, and layer 4- reddish brown clay containing gravel, soft plastic-hard plastic, unspecified thickness, borehole are not finished in this layer (Table 1).

Table 1 Some physical-mechanical properties of soil layers for studied section *[8]*

Parameters	Symbol	Unit	Value		
			Layer 2	Layer 3	Layer 4
Water content	W_w	%	71.8	56.3	29.1
Void ratio	e_0		1.918	1.517	
Saturation degree	G	%	99.8	99.3	
Liquid limit	W_L	%	74.3	62.9	37.5
Plastic limit	Wp	%	43.5	35.1	21.1
Plastic index	Ip	%	30.8		
Liquid index	B		0.92	0.76	0.49
Coefficient of consolidation	C_v	m^2/year	0.117	0.297	
Volumetric compression ratio	m_v	m^2/MN	0.79	0.696	
Pre-consolidated pressure	σ_p	kPa	22.3	58	

For the studied section at km 94+375 road-base is designed B = 54.45 m in width, filling height h_f = 4.1 m, sand mat h_{sm}= 0.8 m; the plug depth of PVD H_d = 13.9 m and spacing between two adjacent PVDs L = 1.1 m. At this section, surface settlement monitoring is installed at the center line, the result of monitoring is shown in Figure 5 shows the settlement process at the center line until 299 days [10].

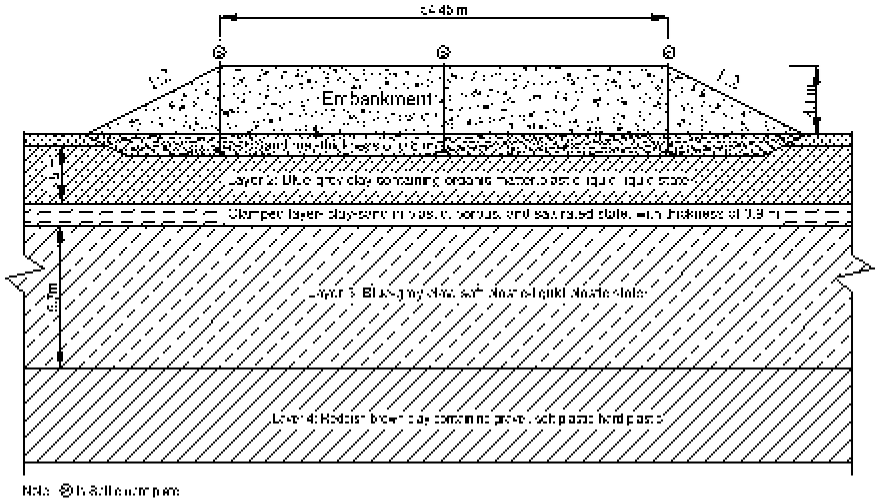


Figure 4 Studied section at km 94+375

From the observational result, it was found that for the initial time after filling enough load, the settlement increased rapidly, however, after 200 days of monitoring, the settlement only slightly increased, it indicated the ground is almost stable.

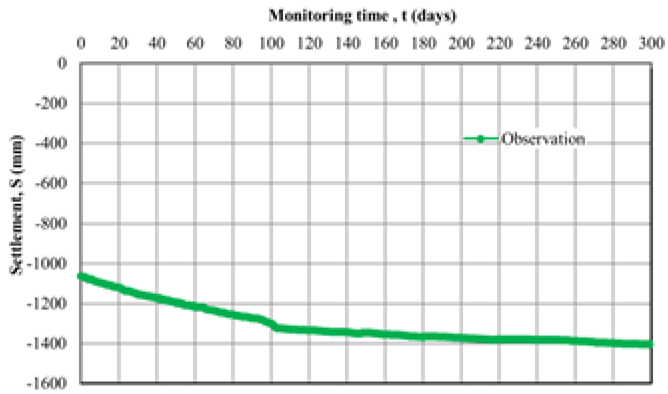


Figure 5 Surface settlement monitoring data at km 94+375 [10]

6. RESULTS AND ANALYSIS

Figure 6 presents the correlation between settlement S_i and S_{i-1} from the observational results. Select calculation time $t_0 = 60$ days with iniital settlement $S_0 = 1217$ mm.

Predict final settlement and consolidation degree using Asaoka method with monitoring cycle $\Delta t = 1$ day. From the graph, it can be seen that the relationship between S_i and S_{i-1} is y = a.x + b, whereas

$$\left.\begin{array}{l} a = 0.9866 \\ b = 18.7938 \end{array}\right\} \Rightarrow S_\infty = \frac{\beta_o}{1-\beta_s} = \frac{b}{1-a} = \frac{18.7938}{1-0.9866} = 1405.71\text{mm}$$

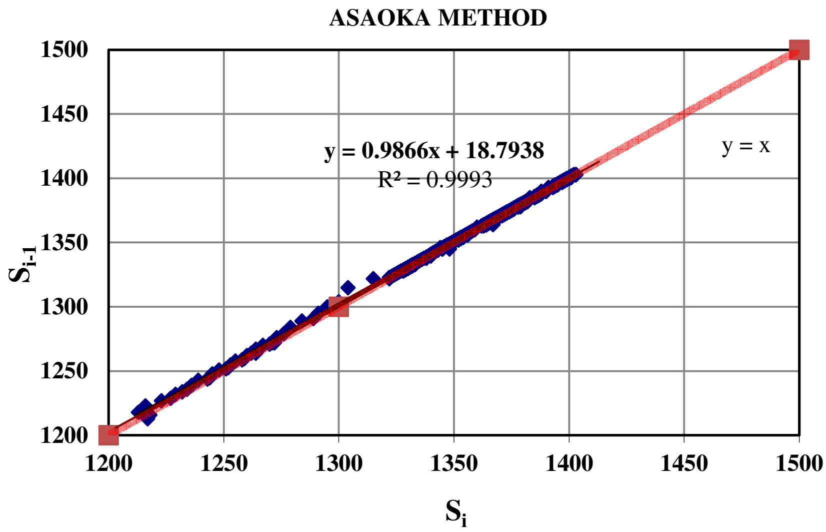


Figure 6 Correlation between S_{i-1} and S_i

Consolidation degree at finishing time of monitoring:

$$U = \frac{S_t}{S_\infty} = \frac{1403}{1405.71} = 99.81\%$$

Where S_t = 1403 mm is the settlement at finishing time of monitoring t = 299 days.

Residual settlement after 299 days

$S_r = S_f - S_t$ = 1405.71 – 1403 = 2.71 mm.

Hanoi-Haiphong highway was designed with velocity $V_{tk} \geq$ 80km/h, the designed requirement for the soft ground treatment as follows:

(i) For normal embankment, the residual settlement (S_r) ≤ 30cm [6].

(ii) Consolidation degree is not smaller than 90% or residual settlement speed is smaller than 2 cm/year [6].

Therefore, by calculating the settlement monitoring result using Asaoka methosd, the final settlement, consolidation degree and residual settlement of studied route are determined. The comparison between the results using Asaoka method and technical design record are summarized in Table 2.

Table 2 Results based on Asaoka method and technical design record

Parameters	Technical design records [9]	By Asaoka Method
Final settlement	1270 mm	1405.71 mm
Residual settlement	12.7 cm	0.271cm
Consolidation degree	90%	99.81%
Time (day)	229	229

Based on the summarised table, it can be seen that the final settlement and the consolidation degree calculated from observational data using Asaoka method are 10.7% and 9.81% larger than those in the technical design record, respectively.

7. DISCUSSION AND CONCLUSION

Evaluating consolidation degree from settlement observation result using Asaoka method is a simple, effective method, this method can reflect appropriately the behavior of soft ground subjected filling load and ground treatment method. The results of this study are only based on surface settlement, therefore, to evaluate with highly reliable and accurate, it is needed to combine with other observation methods such as deep settlement observation, pore water dissipation.

From Table 2, it can be seen that the calculated data from settlement observation was larger than that in technical design records. It implies that loading time and the time point of unloading should be based on many sources to determine the appropriate time to unload.The final settlement result using Asaoka method was 10.7% larger than that in technical design records because of the following reasons (i) when loading is applied, the behavior of different soil layers under the same load is different, because this was not considered in the technical design records., (ii) when loading is applied, the lateral deformation occurred, and resulted in a large settlement, this was assumed in the technical design records., (iii) soil structure is destroyed in the construction process, it is very difficult to determine exactly the principle of destroying soil structure and usually assumed in the calculation, and (iv) the actual model of soft ground behavior in improvement is three-dimension, however, in the calculation, it is assumed to be two-dimension.

From this study, some conclusions can be drawn as follows:

(1) In designing soft ground improvement method using vertical drain combined with pre-loading, it is necessary and important to design and implement geotechnical observation in construction, loading, even in operation stage in order to evaluate consolidation degree and residual settlement of soft ground.

(2) Depending on the geotechnical conditions, construction scale, and properties of embankment works on the soft ground to select properly the content and amount of geotechnical monitoring works.

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