Analysis of Consolidation Settlement: A Case Study on State Islamic University of Sunan Ampel Campus

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Abstract: Analyzing the soil settlement is very important to prevent the civil structure damages. This study revisits a case study of an embankment in UIN Sunan Ampel Gununganyar Campus. The soil investigation was carried out by boring holes until 60 m in depth. Moreover, both Standard Penetration Test (SPT) and Cone penetration Test (CPT) were conducted to know the soil bearing capacity in site and to assess the consolidation parameters on undisturbed and remolded samples. Based on the soil investigation, the grade of the soil from top layer to 3.5 m depth is soft clay with high plasticity (C-H), thus, the layer of 3.5 m to 22.5 m is fine sand that is very loose (S-P). An embankment sand gravel with 2 m height has been placed on the top layer. The consolidation settlement is analyzed by comparing empirical analysis and finite element software Plaxis. The result of the consolidation settlement based on empirical analysis and Plaxis is 0.144 m in 47 days and 0.147 m in 47 days, respectively.

1 INTRODUCTION

As crowded campus in Jl. Ahmad Yani, State Islamic University (UIN) Sunan Ampel has planned to build another campus in Gunung Anyar, Surabaya (Figure 1). Unfortunately, it is not only located in crowded area but also it is laid in the area with low soil bearing capacity, triggering the soil settlement. The soil settlement usually causes damages to the civil structures, e.g., academic buildings, roads, park area, and bridge.

Standard Penetration Test (SPT) and Cone penetration Test (CPT) were conducted in many points of the area with 60 m in depth. The result is that SPT value as well as CPT of top layer at depth of 3.5 m were zero. Soil classification, meanwhile, consists of clay with high plasticity (C-H) from 1 m to clay high plasticity (M-H) from 20.5 m to 60 m respectively

Recently, UIN Sunan Ampel starts the land preparation and embankment work for area of 35.000 m^2 from total area of 400.000 m^2. The embankment height was reach 2 metres from top layer of soft soil or soft ground.

Figure 1: Location map of study area

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Top layer of soil with 3.5 m in depth is highly plastic clay and has very soft consistency. Beneath clay, it is very loose sand 3.5 to 19.5 m and highly plastic silty clay with stiff consistency 19.5 m to 60 m. The settlement will happen if soil material receives many loads. The settlement is strain change in the depth of soil.

$$\Delta H = \int \varepsilon \, dH \tag{1}$$

E = ΔH/H atau ε = σ/Es

Where:
ε = strain ΔH = Settlement
σ = Stress Es = Elasticity Modulus

$$\Delta H = \frac{C_C}{1+e_0} H.log \frac{\sigma'_{vo} + \Delta\sigma_v{}'}{\sigma'_{v0}} \tag{2}$$

$$\Delta H = m_v \Delta\sigma_v{}' H \tag{3}$$

$$m_v \Delta\sigma_v' H = \frac{C_c}{1+e_0} H \, Log \frac{\sigma'_{vo} + \Delta\sigma_v{}'}{\sigma'_{v0}} = \Delta H \tag{4}$$

$$C_c = \frac{m_v \Delta\sigma_v{}'(1+e_0)}{Log\left(\frac{\sigma'_v + \Delta\sigma_v{}'}{\sigma'_{v0}}\right)} \tag{5}$$

m_v= Δe/Δp m_v= 1/E and E= Δp/Δe

$$m_v = \frac{a_v}{1+e_0} \tag{6}$$

Remarks:
Cc: Compression Index
Cv: Consolidation Index
eo: Initial void ratio
Δ σv: External load
Σv': Effective pressure overburden
Pc: Pre-Consolidation Pressure
Mv: Coefficient of soil volume compression
av: Coefficient of pressure

Horizontal settlement equation can be found below

$$\Delta H_c = \mu m_v \Delta\sigma_v{}' H \tag{7}$$

Where μ is affected factor of load area

$$\Delta H \, tot = \Delta H + \Delta H_c \tag{8}$$

$$C_v = \frac{K}{(m_v \gamma_w)} = K(1+e)/(a_v \gamma_w) \tag{9}$$

$$C_v = \left[\frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\sqrt{C_{vi}}}}\right]^2 \tag{10}$$

The relation between degree of consolidation (U) and time factor (T) is shown in table 1.

Table 1: The relation between consolidation degree and time

U	T
00	0.000
10	0.008
20	0.031
30	0.071
40	0.126
50	0.197
60	0.287
70	0.403
80	0.567
90	0.848
100	~

The soil consolidation consists of time consolidation and degree of consolidation. Time of consolidation is

$$t = TH^2/C_v \tag{11}$$

While degree of consolidation is

$$U = \sqrt{T}/\pi \tag{12}$$

Where, T: time factor
t: duration of consolidation

2 RESEARCH METHOD

The study of settlement and consolidation conducted through six steps below:

1. Finding a literature review. A literature is needed to know about basic theory of settlement and consolidation time.
2. Collecting Data. Data used for analysis of the study are soil sampling from embankment and soil beneath embankment.
3. Testing the samples. Material test was conducted by PT. Patron Jakarta. Sampling coincided with

site test SPT and CPT. Literature study is also used to complete unavailable data.
4. Analyzing consolidation settlement. Analysis of consolidation settlement uses geotechnical method and finite element software Plaxis 8.6.
5. Calculating time of consolidations settlement. Calculating time of consolidation uses geotechnical method
6. Giving a recommendation for the owner. The result of the study is expected to give a recommendation, especially for the problem of structures, for the owner.

3 RESULT AND DISCUSSION

The embankment for land preparation and grade layer of soil in UIN Sunan Ampel Gununganyar Campus is shown in Figure 2. The embankment material, sand gravel non plastic must have coefficient of permeability (K) less than 10^{-3} m/day. The property tests from laboratory were unit weight of 20.31 KN/m^3 and water content 12.17%. Material free from colloid or grain-size material over 0.075 mm was 4.8%. The summary of embankment material is shown in table 2 below:

Table 2: The property material of embankment

Soil parameter	Value
ϒ (KN/m^3)	20.31
Water content (%)	12.17
IP (%)	Non Plastic
K (m/day)	< 10^{-3}
Passing size 0.075 mm (%)	4.8

The soil classification of the embankment based on Unified Soil is well grade Sand Gravel (G-W) and specific gravity (Gs=2.69). The soil layer beneath the embankment as shown by figure 2 consists of highly plastic soft clay, loose fine sand, respectively. The material properties of each layer are shown in table 3.

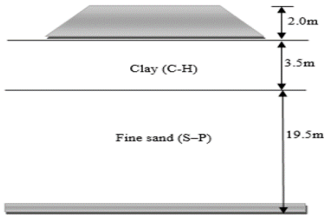

Figure 2: Embankment soil of sand gravel

Table 3: Soil parameter beneath embankment

Parameter	Depth (m)	
	0 - 3.5	3.5- 22.5
Soil Classification	Clay (C-H)	Fine sand
NSPT	0	0
ϒsat (KN/m^3)	14.28	17.85
ϒdray (KN/m^3)	11.34	16.40
Cohesivity (KN/m^2)	19.3	0
Internal Friction angle (ϕ)	7.25	32
E (KN/m^2)	-	20000
K (m/day)	1.43 x 10^{-3}	0.84
Poisson Ratio (μ)	0.25	0.3

Table 3 shows us that two layers of soil beneath the embankment consist of clay, fine sand and clay silt, respectively. The clay layer with 3.5 m in depth has color of grey to black, while the properties of clay are low unit weight, low bearing capacity (NSPT=0), high cohesivity (19.3 KN/m^2) and low permeability (1.43 x 10^{-3} m/day). Under clay layer is fine sand layer. It has black color, high permeability (0.84 m/day) and internal friction angle (32°) but low bearing capacity (NSPT=0).

Figure 3: Bore log soil layer

3.1 Consolidation Settlement Calculation

The calculation of consolidation settlement in this study using equation (2) was to find the result of primary settlement (ΔH), thus it was interpolated degree of consolidation (U) in table 1 to gain the consolidation settlement (Sc), therefore:

$$Sc = U.\ \Delta H$$

The compression index (Cc), coefficient and time of consolidation were derived from equation (4), (9) and (10) respectively.

Table 4: Analysis of Consolidation Settlement

Layer	Depth (m)	eo	Cv) (m^2/day)	Cc
Embankment	2	0.13	NP	NP
Layer 1	3.5	1.56	5.5 x10^{-2}	0.45
Layer 2	19	0.5	NP	NP

The calculation of primary of settlement is shown below:

$$\Delta H = \frac{C_c}{1 + e_o} H \log \frac{\sigma'_{vo} + \Delta\sigma'_v}{\sigma'_{vo}}$$

$$\Delta H = \frac{0.45x3.5}{1 + 1.56} \log \frac{14.28x3.5 + 20.31x2}{14.28x3.5}$$

$$\Delta H = 0.16\,m$$

3.2 Consolidation Time

The calculation of consolidation time used equation (10). The results of consolidation settlement and consolidation time without improvement are shown table 5.

Table 5: The relation between consolidation degree and time for top layer in 0 to 3.5 m depth

Time (day)	Time Factor (Tv)	Degree of consolidation (Uv)	Settlement Consolidation (Sc) (m)
0	0.000	00	0.00
0.45	0.008	0.1	-0.016
1.73	0.031	0.2	-0.032
3.95	0.071	0.3	-0.048
7.02	0.126	0.4	-0.064
10.93	0.197	0.5	-0.080
15.98	0.287	0.6	-0.096
22.44	0.403	0.7	-0.112
31.57	0.567	0.8	-0.128
47.22	0.848	0.9	-0.144

Table 5 explains that based on analytical calculation, top layer of clay 0 to 3.5 m in depth will undergo consolidation settlement (Sc) approximately 0.144 m with degree of consolidation (U) of 90%, thus the time consolidation for pore water dissipation of 90% degree consolidation was 47 days. The consolidation settlement (Sc) and time consolidation (t) experienced by UIN Sunan Ampel embankment is also showed in figure 4.

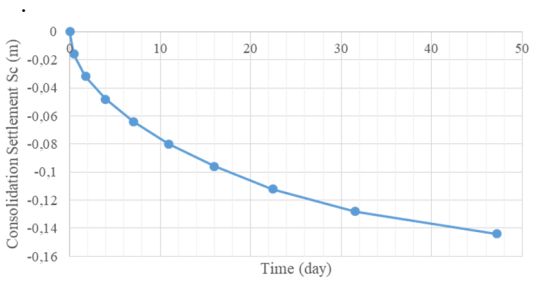

Figure 4: Graph of consolidation time (t) and consolidation settlement (Sc)

3.3 Analysis of Consolidation Settlement using Plaxis Software

In order to convince the consolidation settlement of embankment without any improvement on soft soil and to compare the result of analytical calculation, Plaxis 2D version 8.6 is used for this purpose.

3.3.1 Material Parameters

The material parameters given in table 6 were used for analytical calculation. The embankment can be modelled with Mohr-Coulomb model with parameters: elasticity Modulus (E), Poisson's ratio (μ), internal friction angle ((ϕ), cohesivity (c), and dilatation (Ψ).

Table 6: Paramaeters of Uinsa Soil

Parameters	Embankment	Layer 1	Layer 2
	Sand Gravel	Clay (C-H)	Fine sand
Model	MC	MC	MC
ϒsat (KN/m^3)	20.31	14.28	17.85
ϒdray (KN/m^3)	18.80	11.34	16.40
Cohesivity (KN/m^2)	0	19.3	0
Internal Friction angle(ϕ)	25	7.25	25
E (KN/m^2)	10000	1000	10000
K (m/day)	0.05	1.43 x 10^{-3}	0.84
Poisson's Ratio (μ)	0.3	0.25	0.3

3.3.2 Boundary Condition

The embankment was assumed symmetrical, thus only half of embankment is determined in the finite element analysis as shown in figure 5. The modelled boundary in vertical direction is 25 m in depth and horizontal direction is 25 m. The plane strain condition and fifteen nodes are used.

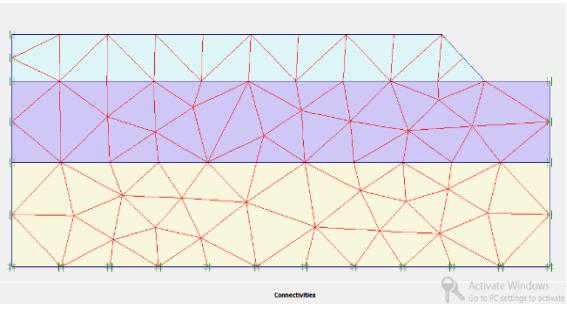

Figure 5: Finite Element analysis mesh

The nodes are only allowed to move in vertical direction and horizontal displacement can be defined

as zero. The excess pore pressure at nodes is set zero. Meanwhile, the lateral boundaries are closed.

3.3.3 Initial Condition and Calculations

Active pore pressure was experienced by layer 1 because water flows from sand layer. Thus, the embankment has only experienced effective stress or there is no excess pore pressure.

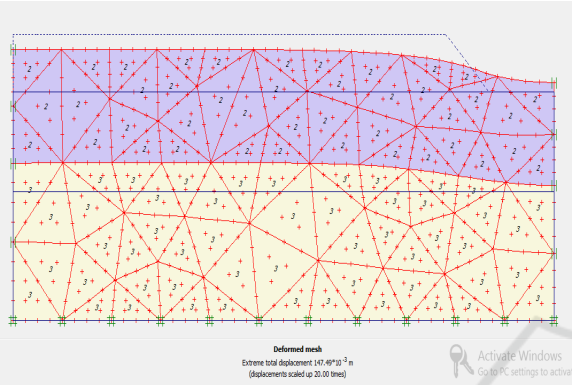

Figure 6: Deformed Mesh of embankment finite element

The result of output of Plaxis as shown in figure 6 is that embankment soil undergoes displacement 0.147 m. The time of consolidation, meanwhile, is 47 days as shown by graph in figure 7.

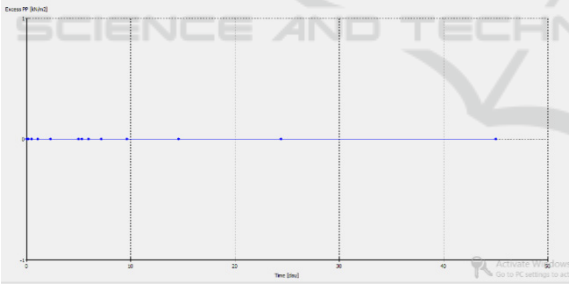

Figure 7: Deformed Mesh of the embankment finite element.

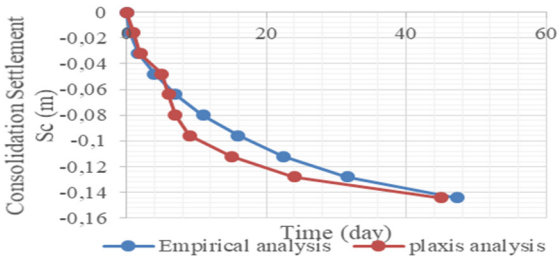

Figure 8: Graph of consolidation time (t) and consolidation settlement (Sc) between empirical analysis and Plaxis

From figure 8, it can be concluded that the consolidation settlement and time consolidation of Sunan Ampel campus embankment are different in empirical analysis and Plaxis program. The result of calculation using Plaxis is lower than analytical calculation but they almost are similar.

4 CONCLUSIONS

Based on the discussion, it concluded that the foundation of embankment of UIN 2nd Campus is soil with low bearing capacity and vulnerable with settlement. It was grey-black clay with high plasticity and low consistency. To avoid structure damages, it is necessary to know the soil characteristics by conducting soil investigation and laboratory test. The result of empirical analysis is that the consolidation settlement of Sunan Ampel Campus embankment is 0.144 m and time with degree of consolidation 90% is 47.7 days. Meanwhile, calculation using Plaxis is 0.147 m in 47 days too. While the result from consolidation settlement and time consolidation analysis should be used for giving some technical recommendations for the owner.

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