Land Subsidence Induced by the Rate of Consolidation of Marine Clay in Kamal Muara Northern Jakarta

Land Subsidence Induced by the Rate of Consolidation of Marine Clay in Kamal Muara Northern Jakarta

L.E Hutabarat[1], **H.R.M Sinaga**[1], **T. Ilyas**[1] **and W.A Prakoso**[1]

[1]Civl Engineering, Universitas Indonesia, Depok, 16424, Indonesia

E-mail: lolom.evalita@ui.ac.id (L.E Hutabarat)

E-mail: hot.raja@ui.ac.id (H.R.M Sinaga)

E-mail: tommy.ilyas@eng.ui.ac.id (T. Ilyas)

E-mail: widjojo.adi@eng.ui.ac.id (W.A Prakoso)

Abstract. The coastal area like Northern Jakarta are developing so fast. This condition will be resulted in land subsidence if soil layers in that area has high compressibility like marine clay layers. Coastal areas of Northern Jakarta generally formed by sedimentary wich are compressible soils. Consolidation is a process of soil compacting due to the compression. Normally consolidated (NC) soil is a type of sedimentary soil that has never experienced a reduction in pressure above it, while over-consolidated (OC) soils are a type of sedimentary soil due to pressure that is much higher than the current pressure. Rate of consolidation is very dependent on compressible parameter. Land subsidence in the coastal area of Northern Jakarta can be estimated by consolidation rate. Therefore, research on the characteristic parameters Cc and Cv compare to plasticity index (PI) of sedimentary soils in the coastal areas of Jakarta needs to be done. This research is conducting by laboratory tests on UDS (undisturbed) soil samples taken by drilling a depth 50 meter point in Kamal Muara area. The method used is the consolidation test for further analysis of the parameters of Cc, and Cv. The result show the land subsidence of marine clay in Kamal Muara Northern Jakarta has a significant correlation with rate of consolidation.

Keywords: compression index, coefficient of consolidation, rate of consolidation

1. Introduction

Soil is not only used for building material, but also as a base construction of a building. When clay is loaded for a long time, it occur land subsidence. Many big cities at the northern coastal area of Java, such as Northern Jakarta develop on river flow estuary area. Geologically, there are alluvial deposits spread on that area. The deposits of weathering and erosion carried away by the river stay on the river estuary. The characteristics of constituent material are based on rocks type eroded by the river. In last 30 years, the subsidence occurs reached 20 – 200 cm at several places, with settlement rates reached 1–15 cm/years [3] [7] [8]. Land subsidence occurs in Northern of Jakarta, especially in areas spread by alluvial deposits [12]. Land subsidence is a decreasing of ground surface level caused by volume changes of soil and rock layers below. This land subsidence can result in structure damages of building. Land subsidence also caused by heavy weights above, such as overburden, buildings weight, and also ground water pumping, massive natural gas extraction, and previous tectonic activity. Clay definition based on Das [4] is a soil type composed by particular particles that can develops plastic behavior in wet condition. Bowles [5] states that cohesion number relates to relative size, grain distribution, and contained clay minerals itself. Clay mineral has a very small size (less than μm) and is a very active particle in electrochemistry. Consolidation is a volume or void decreasing process of saturated soil with low permeability caused by loading, where the process affected by pore water velocity pressed through the soil void. Consolidation commonly occurs in one direction (vertical). Hardiyatmo [7] explained Leonard's research (1962) that shows the best result for load increasing is two times previous load, with load patterns: 0.25; 0.5; 1; 2; 4 ;8; 16 kg/cm^2. Compressibility index related with consolidation or settlement that will be occured. Compressibility index (C_c) represented by the slope of linear equation from e-log p' curve, for two points in the straight line of the curve. C_c number can be calculated by this Equation 1:

$$C_c = \frac{\Delta_e}{logP_2{\prime} - logP_1{\prime}} = \frac{e_1 - e_2}{log\left(\frac{P_2{\prime}}{P_1{\prime}}\right)} \quad \text{[Eq.1]}$$

Where:
C_c = Compressibility index
Δ_e = Void ratio deviation in linear part of e-log p'

Compressibility index correction of e-log p' curve written in Hardiyatmo (2003). Empirical curve as in-situ condition can be drawn by Schmertmann (1953) method. Approaching the original curve in the field can be obtained in the manner proposed by Schmertmann (1953). C_c slope from laboratory result considered as a intersection with line from in-situ testing at void ratio e approaching 0.42 times of previous void ratio e_o. Based on load applied is reviewed from saturated clay layers with height H, the soil layer takes additional stress as Δp.

Consolidation coefficient (C_v) is time needed to complete the consolidation until finish. To calculate C_v in laboratory, we can use time root method by plotting the consolidation result to settlement – time root correlation curve (Taylor 1948). Consolidation coefficient (C_v) and consolidation settlement time (t) can be calculated by this Equation 2:

$$C_v = \frac{T_v {H_t}^2}{t} \quad \text{[Eq.2]}$$

remarks:
t = time
H_t = height of sample
T_v = time factor

2. Methods

This research aims to find compressibility index parameter (C_c), consolidation coefficient (C_v), and identify the correlation with other laboratory test results. Laboratory tests such as consolidation using *oedometer*, specific gravity (SG), and atterberg limits. The soil sample was taken from the District of Kamal Muara, North Jakarta to a depth of 50 meters. Undisturbed samples and disturbed samples are obtained from the results of core drilling. Log-drill correlation is carried out to determine the distribution of each fine clastic material. The N-SPT value obtained will also be correlated with soil compressibility.

Location of research is conducted in Kamal Muara, Penjaringan, North Jakarta (Figure 1). This location is adjacent to the location where is determined by the Department of Mines and Energy DKI Jakarta Province to install extensometer testing instrument up to 300 meters depth. From previous study indicates that deep groundwater extraction (40 - 300 m) is not a major factor causing land subsidence. Geological condition of the Penjaringan area shows that the zone is dominated by embankment and alluvium (Al) which is soft soil with high moisture content. This research is using one-dimensional consolidation testing by laboratory procedure performed in a consolidometer or oedometer was first suggested by Terzaghi [5]. The bore hole up to 50 meter was drilled to determine the SPT value and take undisturbed sample (UDS) of soil from Kamal Muara.

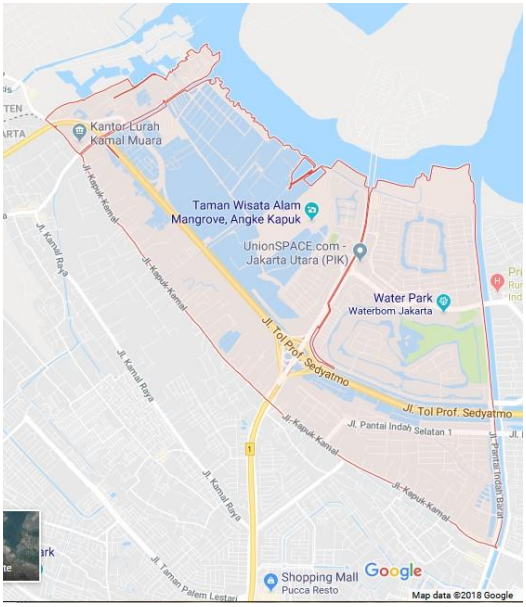

Figure 1. Research Location, Kamal Muara Penjaringan, Northern Jakarta (Source: Google Maps)

3. Results

The index properties test result of disturbed sample explained that soil is identified as soft clay with high water content and void ratio at ground surface to 9.50 meter depth about 78-106%. Soil with high plasticity index 50-55% is classified as CH code which characterized as unorganic clay with high plasticity. Soil at low depth more than 40 meter is classified as stiff clay with high plasticity. Soil at depth more than 40 meter has less void ratio compared to soil at top layers. Laboratory test results shown in this Table 1:

Table 1. Result of Physical Index Properties

Depth (m)	Unit Weight (kN/m^3)	Moisture Content (%)	Void Ratio (e)
4.00-4.50	15.24	78.66	1.20
5.50-6.00	14.41	101.98	1.47
7.00-7.50	14.49	101.60	1.47
9.00-9.50	14.53	106.05	1.54
40.00-40.50	16.22	23.30	0.38
41.50-42.00	18.14	41.05	0.75
43.50-44.00	18.22	82.49	1.5
44.50-45.00	18.21	38.47	0.70

It is clearly seen that soil has high moisture content. As shown in Figure 1, it can be explained that more water content contained will increase void ratio formed in that soil particles. Void ratio can be correlated with soil compressibility index as well.

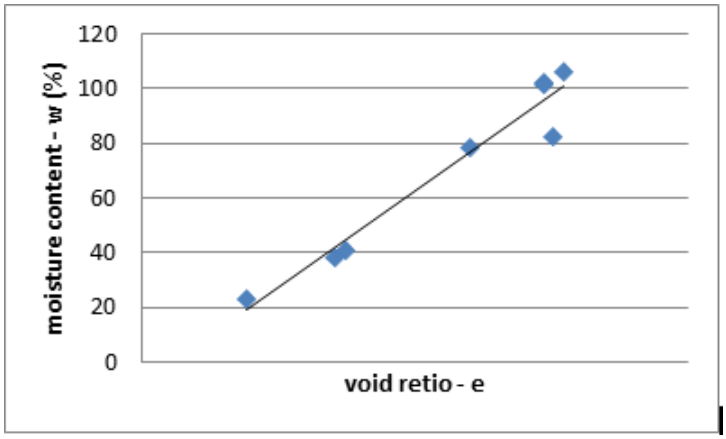

Figure 2. Correlation of moisture content versus void ratio

Bore log test were conducted to collects soil parameters and soil stratification on site. Result of boring log and N-SPT value shown on Figure 3, unit weight and soil physical parameters on every layers shown in table 1.

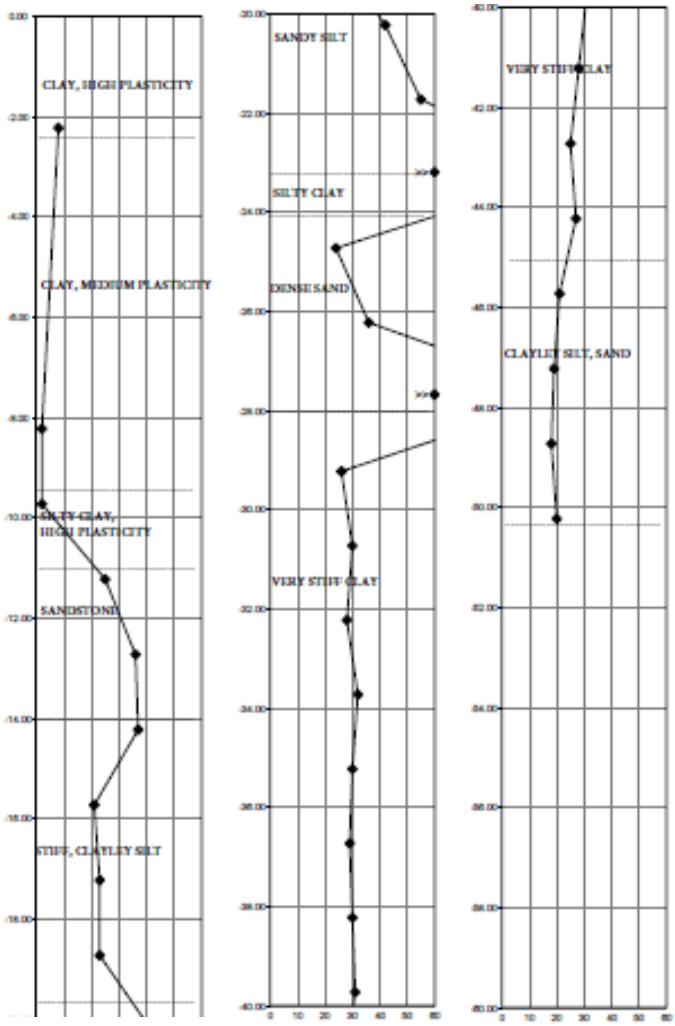

Figure 3. N-SPT and Soil Stratification

Correlation between result of consolidation test withN-SPT can be seen in Table 2

Table 2. Consolidation test result in correlation withN-SPT

Depth (m)	Cc	Cv (cm2/s)	N-SPT
4.00-4.50	0.138	0.0311	2
5.50-6.00	0.213	0.0253	2
7.00-7.50	0.259	0.0245	2
9.00-9.50	0.352	0.0224	2
40.00-40.50	0.198	0.0299	31
41.50-42.00	0.133	0.0332	28
43.50-44.00	0.050	0.0834	27
44.50-45.00	0.087	0.0829	27

4. Discussion

Consolidation test results shown in Table 2 explained that higher compressibility index (C_c) occurred, less time needed by soil to be compressed (Cv). Laboratory test results determined that soil layer with depth above 9.50 meter tend to have high compressibility index (0.138-0.352) with N-SPT 2, in other way to soil layers with depth below 42 meter have low compressibility index with N-SPT 27-31. It can be proved that soil with higher density will have less compressibility index and it will get more time for the soil to be compressed. The consolidation test results attached to table 2 show that the higher the compressibility value (Cc), the less time it takes for the land to be compressed (Cv).

5. Conclusion

Laboratory test results shows that alluvial clay at northern coastal area of Jakarta specifically in Kamal Muara has high compressibility index at surface ground to 9 meters depth, while the soil layers below 42 meters has low compressibility index. This result shows that substructure with shallow foundation has to be designed accurately because soil with high compressibility index indicates that the soil will encounter quick settlement relatively which causes land subsidence affected to structure damages. Laboratory tests are mandatory due to designing building structures or building with high utility so the settlement that causes land subsidence can be calculated and minimized properly.

Acknowledgements

Acknowledgments and gratitude to all the parties who have assisted and supported the research of Site Characterization of Marine Clay Compression Index on Kamal Muara Area, Northern Jakarta, especially to research grant from PITTA Universitas Indonesia with Contract No. 2547/UN2.R3.1/HKP.05.00/2018

Appendix

[1] American Society for Testing and Materials, *Annual Book of ASTM Standard, Section 4 Consrtuction, Volume 04.08,Soil and Rock (I)*, ASTM European Office, England, 1997
[2] A. H. M. Ng, L. Ge, X. Li, H. Z. Abidin, H. Andreas, dan K. Zhang, "Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR," Int. J. Appl. Earth Obs. Geoinf., vol. 18, no. 1, hal. 232–242, 2012.
[3] A. Syarifudin, "Perubahan Parameter Konsolidasi Tanah Lempung Tanon Yang Dicampur Abu Ampas Tebu", e-Jurnal Matriks Teknik Sipil Vol. 1 No. 4, Universitas Sebelas Maret, Surakarta, 2013
[4] B.M Das, "Principles of Geotechnical Engineering", Adapted Int Student Edition, Thomson, p.137, 2007
[5] Craig, R. F. "Soil Mechanics (4th edi.)." *ELBS Edition, Great Britain*, 1987
[6] E. Chaussard, F. Amelung, H. Z. Abidin, dan S. H. Hong, "Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction,"Remote Sensing Environment"., vol. 128, hal. 150–161, 2013.
[7] H. Z. Abidin, H. Andreas, R. Djaja, D. Darmawan, dan M. Gamal, "Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys," GPS Solut., vol. 12, no. 1, hal. 23–32, 2008
[8] H.C. Hardiyatmo, "*Mekanika Tanah"*, Gramedia Pustaka Utama, Jakarta, 1992
[9] H.C. Hardiyatmo, "*Mekanika Tanah II"*, Gadjah Mada University Press, Yogyakarta,

2003
[10] L. E. Hutabarat dan T. Ilyas, “Mapping Of Land Subsidence Induced By Groundwater Extraction In Urban Areas As Basic Data For Sustainability Countermeasures,”Int J. Technology”., vol. 6, hal. 1001–1011, 2017
[11] R.I. Sophian, “Penurunan Muka Tanah Di Kota-Kota Besar Pesisir Pantai Utara Jawa (Studi Kasus: Kota Semarang)”, Laboratorium Geologi Teknik Universitas Padjajaran, Bandung, 2002