Journal of Physics: Conference Series

Estimation of Settlement Induced Land Subsidence of Marine Clay on Kamal Muara Area, Northern Jakarta, Based on the Change of Pore Water Pressure

To cite this article: F M L Taqwa *et al* 2019 *J. Phys.: Conf. Ser.* **1376** 012007

Estimation of Settlement Induced Land Subsidence of Marine Clay on Kamal Muara Area, Northern Jakarta, Based on the Change of Pore Water Pressure

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Abstract. Land subsidence phenomena which occurred in last 30 years in Jakarta affected by groundwater extraction, settlement of high compressibility soil such as marine clay, natural consolidation of alluvial soil or tectonic subsidence. Over the period of 1982–1997, the subsidence occurred from 20 to 200 cm, with the rates of about 1 to 15 cm/year, in several places. This paper discusses settlement induced land subsidence of shallow marine clay deposits on Kamal Muara area, based on the pore water pressure changes based on the piezometer's measurement located at 19 meters and 32 meters depth. Consolidation parameters (Cv and Cc) tested by cyclic load consolidation test. The estimation of on-site land subsidence is performed using the Terzaghi's 1-D consolidation theory and the secondary compression theory. Ranges of estimated values, as well as their relevant statistical properties, were identified. The results shown as follow: Without water extraction, settlement on soil layer #1 and #2 estimated as 0.647 meters and 0.305 meters respectively, with average subsidence rate is 9.832 cm/year and 1.07 cm/year. Total settlement estimated as 1.01 meters, with average subsidence rate is 5.07 – 5.42 cm/year. With water extraction, settlement on soil layer #1 and #2 estimated as 0.658 meters and 0.395 meters respectively, with average subsidence rate is 10.005 cm/year and 31.88 cm/year. The subsidence on Kamal Muara estimated as 0.68 – 1.05 meters, with subsidence rate 5 – 20.9 cm/year. The results placed on the lower range of field geodetical measurements, due to specific values of surface load and pore water measurement on Kamal Muara is used specifically.

Keywords: Land subsidence, marine clay deposits, consolidation parameters, pore water pressure changes.

1. Introduction

Land subsidence has been identified as one of major geological hazards of Jakarta. In last 30 years, the subsidence occurs reached 20 – 200 cm at several places, with settlement rates reached 1 – 15 cm/years. [1–3]. The land subsidence that occurs is influenced by the following factors, such as: groundwater extraction, structural load on compressive soil, consolidation on alluvial soils, and tectonic activity. The impact of the land subsidence can be categorized as a structural, environmental, economic and social impact. Examples of damage can occur in the form of cracks and damage to homes, other buildings and infrastructure, expansion of flooded areas, failure of drainage systems, changes in river channels, and expansion of seawater intrusion areas [4].

Judging from the character of geology, there are five (5) zones of geological formations in Jakarta, namely: (1) alluvial volcanic fans, which is located in the southern of Jakarta, (2) the marina formation, located on the northern coast of Jakarta along the coastline, (3) beach ridge, in the northwest and northeast, (4) Swamps and mangroves, and (5) river formations, located along the river basin. Three layers of aquifer were found at a depth of 0 - 40 meters (upper aquifer layer), 40 - 140 meters (middle aquifer layer) and 140 - 250 meters (bottom aquifer layer). [5]

The biggest subsidence occurred in the North Jakarta area, with a subsidence rate up to 20-25 cm/year. This area is the most developed in the last decades as a residential, industrial area, tourism, and port. To meet the development demands, several areas have been reclaimed. The land subsidence that occurred, especially in North Jakarta, had a big impact on various sectors, and if it associated with sea level rise, the subsidence could be hazardous to the surrounding population. [6]

North Jakarta area is dominated by alluvial marine clay formation. In particular, marine clay classified as soft soil and consolidate easily due to additional surface loads. Thus, a special study is needed that examines the effects of the consolidation process on marine clay and the settlement that occurred, especially in North Jakarta.

2. Research method

This study will examine the extent of consolidation that occurs on marine clay, and added to subsidence that occurs on the surface. The study was conducted by measuring the changes of the water pore pressure on marine clay deposit in Kamal Muara, North Jakarta. The piezometer instruments for this purpose was located on 19 meters and 32 meters depth from the surface. The cyclic laboratory consolidation test was conducted on Undisturbed Samples (UDS) on the respective depth to determine the consolidation parameters (Compression Indexes Cc, and Consolidation Rates, Cv) of marine clay soil. Using Terzaghi 1-D consolidation and the secondary compression theory, the estimation of on-site land subsidence is performed. For the simulation purpose, different value of embankment height is used as surface loads. The research method is shown on figure 1.

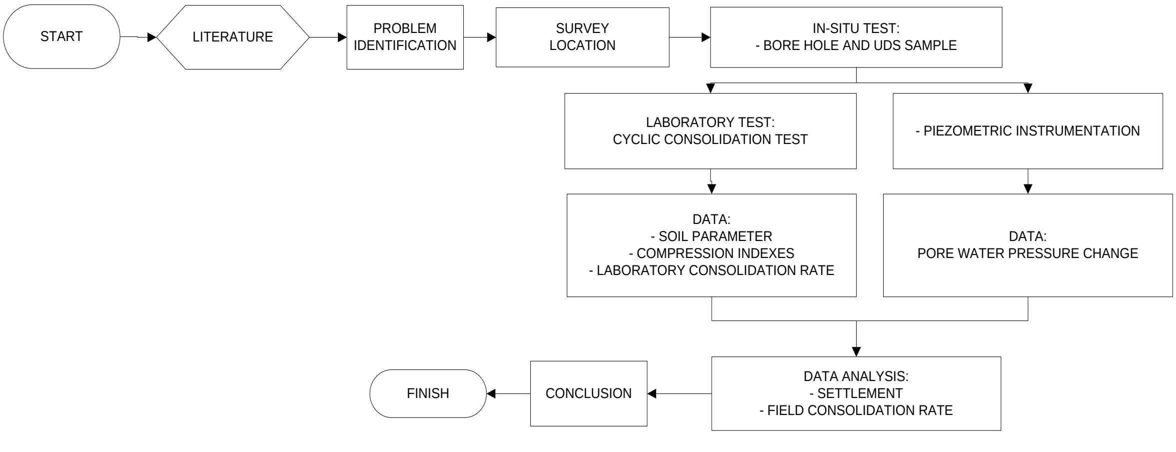

Figure 1. Research Method Flowchart

Research on compressibility parameters in clay soil (*Cc*, *Cv*) was carried out using a mathematical approach and statistical regression of various physical parameters of clay soil (e_0, *LL PL* and *PI*) [7], but no studies that measure the pore water pressure changes based on the results of piezometers were compared with the results of testing in the laboratory consolidation. To determine the value of *Cc* and *Cv*, cyclic consolidation test is conducted to soil sample, using modified testing models developed by Vinod and Sridharan [8], based on Asaoka's mathematical model.

The settlement estimation procedure conducted using the Terzaghi's 1-D consolidation theory and the secondary compression theory [9]. The estimation of consolidation settlement *Sc*, shown on equations below:

$$S_c = \frac{C_c}{1+e_0} H_{soft} \log \frac{\sigma'_{final}}{\sigma'_{initial}} \tag{1}$$

$$\sigma'_{final} = \sigma'_{initial} + (\gamma_{soft} . H_{fill}) \tag{2}$$

$$\sigma'_{initial} = (\gamma_{soft} - \gamma_{water}).(\frac{H_{soft}}{2}) \tag{3}$$

Where C_c is compression ratio, e_0 is initial void ratio, H_{soft} is thickness of soft soil, γ_{soft} is saturated unit weight of soft soil, γ_{water} is unit weight of water, γ_{fill} is unit weight of fill material and H_{fill} is height of embankment. The time to reach a certain consolidation time, *t*, is estimated using equations **Error! Reference source not found.**:

$$t = T_v \frac{(H_{soft}/2)^2}{c_v} \tag{4}$$

In which T_v is theoretical time factor and c_v is coefficient of consolidation. The theoretical relationship between the degree of consolidation *U* and the time factor T_v shown in [9] is adopted.

The magnitude of secondary settlement at time *t* is estimated by the following equations:

$$S_s = c'_\alpha H \log \frac{t_2}{t_1} \tag{5}$$

$$c_\alpha = \frac{\Delta e}{\log(t_2/t_1)} \tag{6}$$

$$c'_\alpha = \frac{c_\alpha}{1+e_p} \tag{7}$$

In which c'_α is coefficient of secondary compression, and e_p is void ratio at the end of primary consolidation. The rate of subsidence on site can be estimated by the following equations.

$$SubsidenceRate = \frac{[S_{c(t1)} - S_{c(t2)}]}{(t_2 - t_1)} \tag{8}$$

$$SubsidenceRate = \frac{[S_{s(t1)} - S_{s(t2)}]}{(t_2 - t_1)} \tag{9}$$

In which t_1 and t_2 is earlier time and latter time, respectively. It is noted that three implicit assumptions in the above equation for simplicity. First; the groundwater table is assumed to be at the ground surface level, very reasonable for Northern Jakarta area. Second; the induced load is due the placement of the fill layers, not from structural loads, because the surcharge load from building or structures usually supported by deep foundation system such as piles. And third; the changes of pore water pressure at time *t* which monitored by piezometric instrument ($\Delta u_{(\Delta t)}$), will be carried by effective stress of soil particles, hence ($\Delta u_{(\Delta t)} = \Delta\sigma'_{(\Delta t)}$).[10]

The research is conducted in Kamal Muara, Penjaringan, North Jakarta. The location shown in **Figure 2**, the location is chosen due the exact location of extensometers testing conducted by the Department of Mines and Energy Prov. DKI Jakarta, at 120 meters' depth. The piezometers instruments located in 19 meters and 32 meters' depth from the surface to collect pore water pressure data. The piezometers and data logger shown in **Figure 3**.

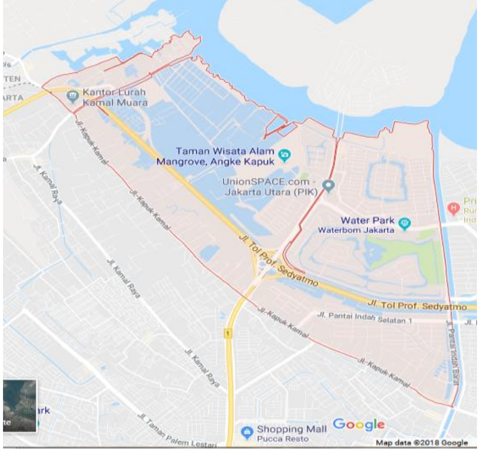

Figure 2. Research Location, Kamal Muara, Penjaringan, Northern Jakarta (Source: Google Maps)

Figure 3. Piezometric Instrument and Data Logger Set

3. Data analysis and result

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 4, unit weight and soil physical parameters on every layer shown in Table 1 and the result of pore water pressure monitoring from May to August 2018 shown in Figure 5.

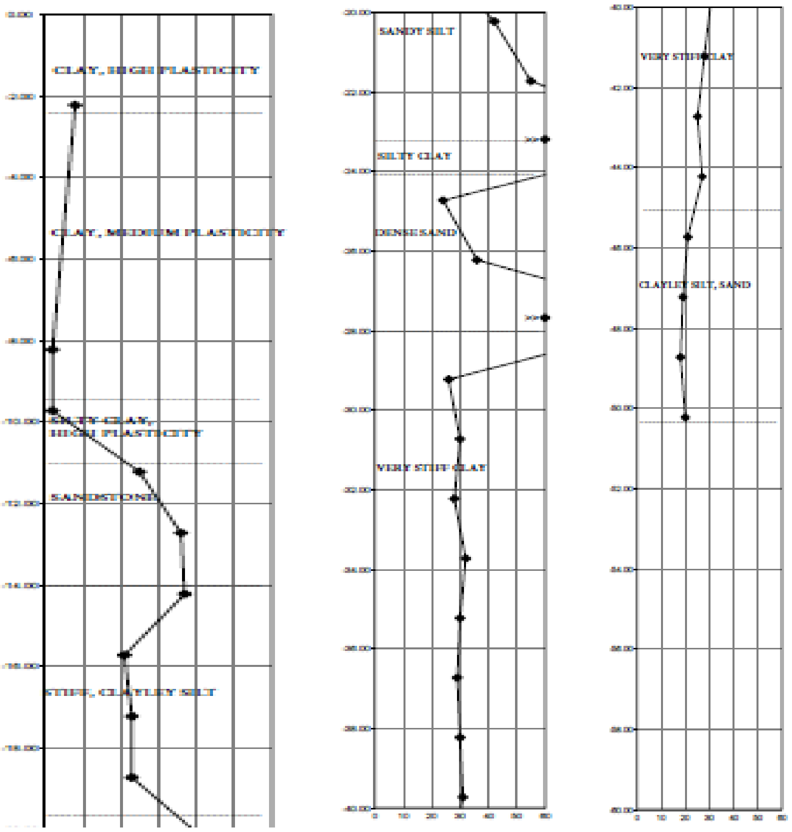

Figure 4. N-SPT value and soil stratification

Table 1 Soil Parameters

depth	4.00	5.50	7.00	average	40	41.5	43.5	44.5	average
w_n	78.65%	101.98%	106.06%	95.56%	23.30%	41.05%	82.49%	38.47%	46.33%
γ_{sat}	0.0015	0.0014	0.0015	0.0015	0.0016	0.0018	0.0018	0.0018	0.0018
e_0	0.0012	0.0015	0.0015	0.0014	0.0004	0.0007	0.0015	0.0007	0.0008
C_c	0.1966	0.1740	0.1059	0.1588	0.1966	0.1740	0.1059	0.1192	0.1489

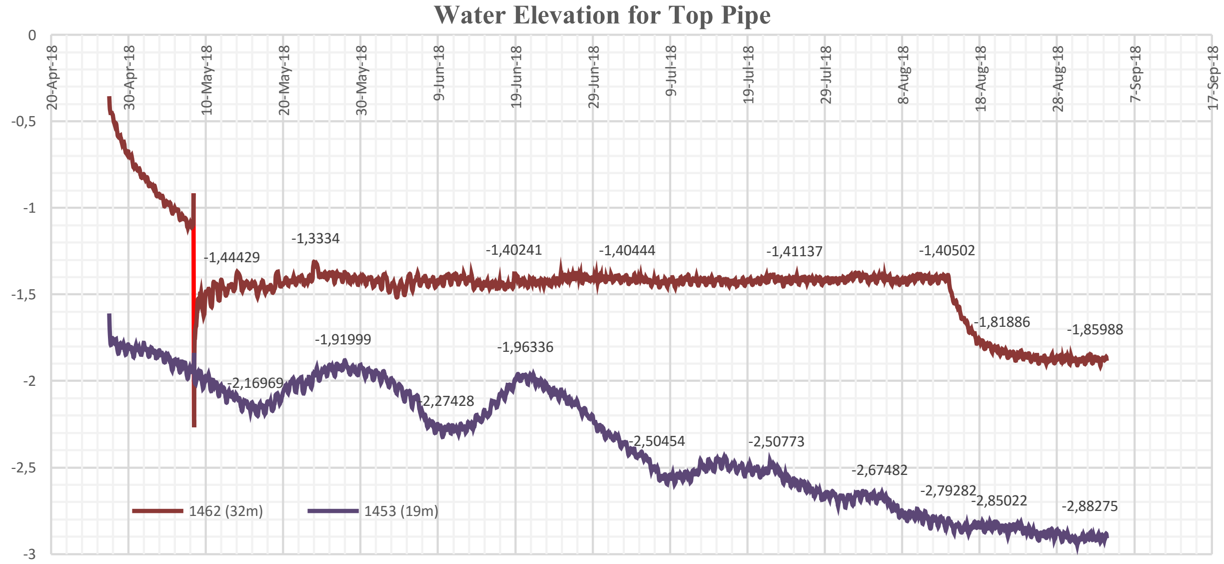

Figure 5. Pore Water Pressure Changes from May to August 2018

As shown on **Figure 5**, at first, fluctuation of water pressure happened on 19 meters depth, due to the gap between soil and hole casing not yet closed, *hypothetically,* so got affected by tidal wave, but became more stable at later date. Pore-water measurement on 32 meters' depth not affected by hole gap, so the measurement became stable from early date. Water pressure decreased so suddenly on Medio August 2018, due to extraction of water for daily needs on dry season.

Table 2 Pore Water Pressure Change from July 2018

Time	Pressure (KPa)		Pressure Head (m)		duration (days)	pressure lost (m)		pressure lost rate (m/day)	
	19 m	32 m	19 m	32 m		19 m	32 m	19 m	32 m
07-07-18	1.6248	3.0984	-2.5524	-1.4261					
08-08-18	1.6040	3.0999	-2.7600	-1.4111	31.46	0.208	-0.015	0.006599	-0.000477
21-08-18	1.5966	3.0586	-2.8343	-1.8241	44.54	0.282	0.398	0.006329	0.008935
03-09-18	1.5892	3.0526	-2.9079	-1.8841	57.58	0.356	0.458	0.006175	0.007954

From the **Table 2** above, the water pore pressure change is counted from First week of July 2018 which water is gradually dissipated and not randomly fluctuated. At 19 meters depth, the water pore pressure change (Δu_{19}) is measured as 0.356 meters head, and at 32 meters depth, the pressure change (Δu_{32}) is measured as 0.458 meters head.

The estimation of settlement is conducted on both soft soil layers. Following the equation, without water dissipation, the consolidation on soil layer #1 (4.0 – 23 m depth) estimated as 0.647 m, with subsidence rate estimated as 9.832 cm/year. The primary consolidation will be finished after 6.58 years and secondary compression after 10 years estimated as 0.035 m. The total settlement after 10 years is 0.682 m, with subsidence rate as 6.82 cm/years. Without water dissipation, the consolidation on soil layer #2 (28 – 45 m depth) estimated as 0.305 m, with subsidence rate estimated as 1.07 cm/year. The primary consolidation will be finished after 19.82 years and secondary compression after 30 years estimated as 0.017 m. The total settlement after 30 years is 0.682 m, with subsidence rate as 1.07 cm/years. Total settlement on both layers estimated as 1.01 meters, with average subsidence rate is 5.1 – 5.42 cm/year.

If water extraction on Kamal Muara area still happened, in near future, the settlement on shallow layer estimated as 0.658 meters, with subsidence rate estimated as 10.005 cm/year. At deeper soil layer, the settlement estimated as 0.395 meters, consolidation should be finished on 1.24 years, with subsidence rate estimated as 31.88 cm/year. Total settlement on both layers estimated as 1.053 meters, with the average rate of subsidence is 15.2 - 20.9 cm/year.

4. Conclusion

Land subsidence has been identified as one of major geological hazards of Jakarta. The hypothesis of this paper was that the subsidence is predominantly due to the compression of the normally consolidated, very soft to soft marine clay deposits induced by pore water pressure change. Based on laboratory and field instrumentation data, the range of settlement on 2 (two) layers of marine clay is estimated. The subsidence on Kamal Muara estimated as 0.68 – 1.05 meters, with subsidence rate 5.1 – 20.9 cm/year. The results placed on the lower range of field geodetical measurements, due to specific values of surface load and pore water measurement on Kamal Muara is used specifically.

5. Acknowledgments

Acknowledgments and gratitude to all the parties who have assisted and supported the research of Estimation of Settlement Induced Land Subsidence of Marine Clay on Kamal Muara Area, Northern Jakarta, Based on the Change of Pore Water Pressure, especially to research grant from PITTA Universitas Indonesia with contract No. 2547/UN2.R3.1/HKP.05.00/2018.

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