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POTENTIAL CONSOLIDATION SETTLEMENT DUE TO LOAD STRESSES OF BUILDING STRUCTURES

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ABSTRACT: Semarang is a capital city of Central Java province in Indonesia, in which mostly dominated by large lowlands at coastal areas that formed by alluvial fan and flood-plain of thick clayey soil as Quaternary deposits. The thick clayey soils deposits encountered in the coastal areas are having a high compressibility behavior and categorized as normally consolidated clays. Presence of building structures for public facilities, heavy industry, residential areas, and the other infrastructures subsequently accelerates consolidation settlement in a large part of the northern Semarang city. This research is intended to reveal rates of potential consolidation settlements due to load stresses impact of building structures by means of one-dimensional settlement calculation method based on the compressible features of the clayey soils. The settlement phenomenon is extensively caused by the presence of voids in the soil structure that contributing to the existence of compression index (C_c), the thickness of the compressible clayey soils, and surcharges load of building structures. By simplifying the surcharge load model of the light structure about 15 kPa, then for medium and heavy structure about 35 and 60 kPa, hence the potential consolidation settlement of light, medium, and heavy structures are about 1.42, 2.90, and 4.38 cm, respectively.

Keywords: Consolidation settlement, Compressibility, Land subsidence, Clay, Semarang

1. INTRODUCTION

Administratively, Semarang is a capital city of Central Java province. It is located in the northern coast of Java island, Indonesia, with the region in between of coordinates 6°30’–7°00’ latitude and 110°15’–110°30' longitude and total area rounded about 390 km^2. The northern part of Semarang city is mostly dominated by a large lowland and coastal areas formed by alluvial fan and flood-plain as clayey soils of Quaternary deposits in geological time scale in which the thickness of the deposits are more than 120 meters [1].

Topographically, Semarang city consists of two major landscapes, namely lowlands and coastal areas in the northern part and hilly regions in the southern part. Estuarine and coastal zones are important areas for human survival and socio-economic development [2].

In the northern part, it comprises of the center of Semarang city, harbour, airport, and a railway station that relatively flat with the topographical slopes ranging between 0–2°, and altitude position between 0–3.5 meters above mean sea level.

The northern part, it has relatively a higher population density and also more industrial, public services, and business areas as well compared to the southern part. The land use of the southern part consists of residential, offices, retail, public use, and open space area. There are two rivers splitting the city, one on the east side and the other one on the west side which essentially divides the city into three parts [2]. Geologically, the northern part of Semarang city as a focus of the discussion in which dominated by alluvial deposits is consists of two large lithologies namely Damar Formation (QTd) and Alluvium (Qa) that spread widely in the lowland and coastal areas.

The Damar Formation (QTd) is unconformably deposited over Kalibeng Formation which consists of feldspar and mafic mineral, partly tuff and limestone, tuff breccia, conglomerate, and volcanic breccia as laid on Tembalang, Candisari, Gajah-mungkur, and Ngaliyan; meanwhile the Alluvial deposit (Qa) constitutes a recent sedimentary deposits from fluviatile materials, flood-plain, and coastal deposit that consists of a high compressible clay and silty soils, gravelly-silt, cobble-sand, and mixed-sand on Pedurungan, Gayamsari, Genuk, until Tugu as shown in Figure 1.

In some different references, land subsidence of Semarang city is expected caused by the natural consolidation process of compressible and high plasticity soil surrounding the flood-plain, tidal areas, and near-shore deposits. The subsidence is categorized as a geological hazard which causes the ground elevation dropped slowly and may lead to a disaster [4]. The subsidence in Semarang city has been extensively studied from many aspects i.e. geodetic monitoring, groundwater extraction, and engineering geology. The land subsidence in this case threats and its management should be in the North Coast of Java [5].

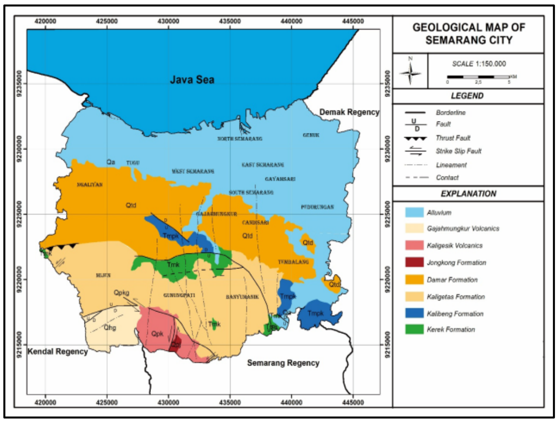

Fig.1 Geological map of Semarang city modified from Thaden et al., 1996 [3]

The land subsidence rates of Semarang city had been presented by Abidin, et al., 2010 [6] in which the worst land subsidence occurred in the northern areas closest to Java sea with the subsidence rate more than 8 cm per annum. The contour lines as shown in Figure 2 are based on the PS InSAR (courtesy of Geological Agency of Indonesia) based velocity data derived from 28 ERS-2 and ENVISAT-ASAR radar scenes as recorded between the date of 27 November 2002 and 23 August 2006.

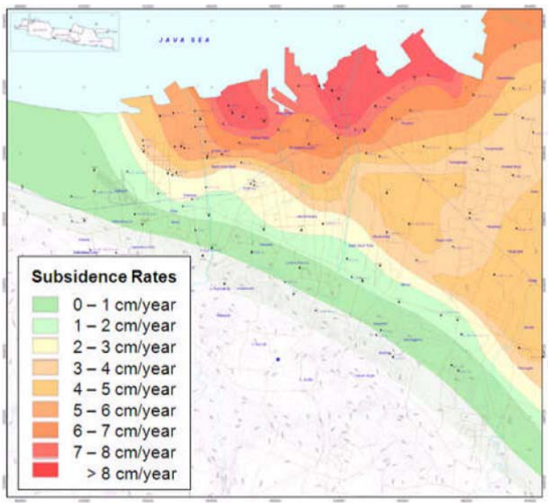

Fig.2 PS InSAR derived land subsidence rates in Semarang city presented by Abidin, et al., 2010 [6]

According to Abidin, et al. 2013 [7], the Alluvial deposits which encountered in the coastal areas of Semarang city consists of beach, flood-plain, tidal, near-shore, and alluvial fan deposits as illustrated in Figure 3.

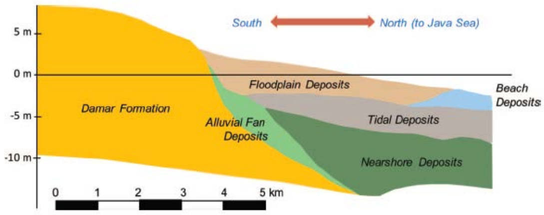

Fig.3 Cross section of Quaternary geological of Semarang city [7]

Referring to some unpublished data as being collected from individual researches mainly in the coastal areas (in this research taken from Tambak Lorok and vicinity), the soils are commonly a clay high plasticity (CH) with compressibility index (C_c) are relatively high within range of 0.166 to 1.044 (average value about 0.51 for 0.0–30.0 m depth and 0.26 for deeper than 30 m). The clays are an important constituent of soils, which evolve mainly from chemical weathering of rock-forming minerals, and regarded as fine-grained soils in geotechnical engineering [8-10].

Unit weight of the dry soils (γ_d) are ranging in between of 8.1–12.8 kN/m^3 and in wet condition (γ_{wet}) are ranging from 15.3–18.7 kN/m^3, and the average value of the overconsolidated ratio (OCR) is 0.52 means the soils commonly consist of normally consolidated clays. Saturation degrees of the clayey soils (S_r) are relatively high with the values of more than 95%. Mechanical properties of the soils in effective condition are such as cohesion (c') about 10–15 kPa and angle of internal friction (φ') about 10–25°.

Zoning and subdivision of the coastal areas for construction and development involve several stages [11]. These include an identification of the natural and manmade ground conditions such as lithostratigraphy, geological studies [12], soils geomorphology, geotechnical characteristics, hydrology [13], land-use, and potential natural hazard assessment.

In terms of the determination of surcharge loads design of the building structures to predict potential consolidation settlement in this scope of research, some published standard or building codes are used as a reference to determine dead loads and live loads of the structural design. Dead loads are defined as the weight of materials of construction incorporated into the building, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, and the weight of fixed service equipment, such as cranes, plumbing stacks and risers, electrical feeders, heating, ventilating and air-conditioning systems, and automatic sprinkler systems, meanwhile live loads are defined as those loads produced by the use and occupancy of the building or other structure and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load [14].

For engineering purposes, the dead loads must be calculated individually on respective structures due to high variability in terms of material specifications used, dimension, and others, but for rough estimation, the dead loads are assumed based on our common senses such as 15 kPa for light structure, 45 kPa for medium structure, and 60 kPa for heavy structure. The live loads is distinguished into two types: (1) uniform live loads, is used in the design of buildings and other structures shall be the maximum loads expected by the intended use or occupancy but shall in no case be less than minimum uniformly distributed unit loads required, and (2) concentrated loads, is floors and other similar surfaces shall be designed to support the uniformly distributed live loads or concentrated loads. The requirements of minimum uniformly distributed live loads and minimum concentrated live loads of several buildings are shown in the following Table 1.

Table 1 Minimum uniformly distributed live loads and minimum concentrated live loads. [15]

Occupancy or Use	Uniform psf (kN/m^2)	Concentrated lbs. (kN)
Residential:		
All other areas except stairs and balcony	40 (1.92)	-
Hotel and apartment, public rooms and corridors serving them	100 (4.79)	-
Office Building:		
Lobbies and first-floor corridors	100 (4.79)	2,000 (8.9)
Corridors above the first floor	80 (3.83)	2,000 (8.9)
Hospital:		
Operating rooms, laboratories	60 (2.87)	1,000 (4.45)
Corridors above the first floor	80 (3.83)	1,000 (4.45)
Manufacturing and warehouse:		
Light	125 (6.00)	2,000 (8.90)
Heavy	259 (11.97)	3,000 (13.40)
Stores:		
Retail (first floor)	100 (4.79)	1,000 (4.45)
Wholesale, all floors	125 (6.00)	1,000 (4.45)

Typical clayey soils in the region are commonly normally consolidated clays with soft consistency in considerable depth which have never been subjected to effective stress greater than present effective overburden pressure means the clayey soils is unconsolidated materials. It also tends to have a behavior of sensitive to the effects of disturbance that can influence the relationship between volumetric changes and normal stress i.e. load stress, surcharge loads, and overburden pressure. In line with the rapid growth of the city and the increase of the population in the last decades made a change of groundwater abstraction patterns and increasing of surcharge loads as well due to presence of building structures for public facilities, residential, mix-use, heavy industries, and other infrastructures subsequently accelerates consolidation settlement in the large part of Semarang city.

Through this article, it can be developed a discussion about potential consolidation settlement in the city due to an additional surcharge loads from light to heavy structures in which the structures assumed seated on shallow foundations by assuming the consolidation settlement occurs in normally consolidated clayey soils, predetermined load pressure about 15, 35, and 60 kPa, and the pore-water pressure considered to be dissipated.

2. METHODOLOGY

Commonly, the clayey soils have compressible behaviors due to the presence of a void in the soil structure itself. The application of a load to an unsaturated soil specimen will result in the generation of excess pore-air and pore-water pressures in which the excess pore-water pressures will dissipate with time, and will eventually return to their values prior to loading; the dissipation process of pore-water pressures is called consolidation, and the process results in a volume decrease or settlement [16]. When the soils loaded by an overburden pressure as well, it may cause a change in a volumetric soil that represented by decreasing of the void ratio (e). For example, when a clay layer of total thickness H_t is subjected to an increase of average effective overburden pressure from σ'_0 to σ'_1, it will undergo a consolidation settlement of ΔH_t in which the strain can be given by the following equation:

$$\in = \frac{\Delta \boldsymbol{H_t}}{\boldsymbol{H_t}} \quad (1)$$

where $\in$ is a strain. If an undisturbed laboratory specimen is subjected to the same effective stress increase, the void ratio ($\boldsymbol{e}$) will decrease by $\Delta\boldsymbol{e}$; thus the strain is equal to:

$$\epsilon = \frac{\Delta e}{1 + e_0} \qquad (2)$$

where e_0 is the void ratio at an effective stress of σ'_0.

To calculate a consolidation settlement (S_c) on clayey soils, Das (2008) [17] has derived one-dimensional primary formula in the following equation:

$$S_c = \Delta H_t = \frac{\Delta e}{1 + e_0} H_t \qquad (3)$$

for normally consolidated clays:

$$\Delta e = C_c log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_0} \qquad (4)$$

for overconsolidated clays,

$$\Delta e = C_r log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_0} \qquad (5)$$

for $\sigma'_0 < \sigma'_c < \sigma'_0 + \Delta\sigma$:

$$\Delta e = C_r log \frac{\sigma'_c}{\sigma'_0} + C_c log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_c} \qquad (6)$$

where ΔH_t is a consolidation settlement, H_t is total thickness of the clayey soils, Δe is decrea ase of void ratio, e_0 is initialan void ratio, σ'_0 is preconsolidation pressure, σ'_c is loads pressure, $\Delta\sigma$ is different between loads pressure and preconsolidation pressure, meanwhile C_c is compression index (slope of the $e - log\,\sigma$ curves or change in void ratio per unit change in logarithm of verticthe al effective stress in virgin compression range) and C_r is recompression index (slope of the $e - log\,\sigma$ rebound/reloaded curves or change in void ratio per unit change in logarithm of vertical effethe ctive stress in recompression range) according to Michael, *et al.* (1976) [18].

3. RESULT AND DISCUSSION

The following Table 2 is a compilation of geotechnical investigation results in the northern part of Semarang city as collected from some different sources to obtain characteristics and parameters of the soils and to calculate the behavior of the potential consolidation settlement at the northern part of Semarang. To simplify the analysis, the clayey soils deposits are divided into two layers based on the configuration of the compression index (Cc) versus depth as shown in Figure 4 below.

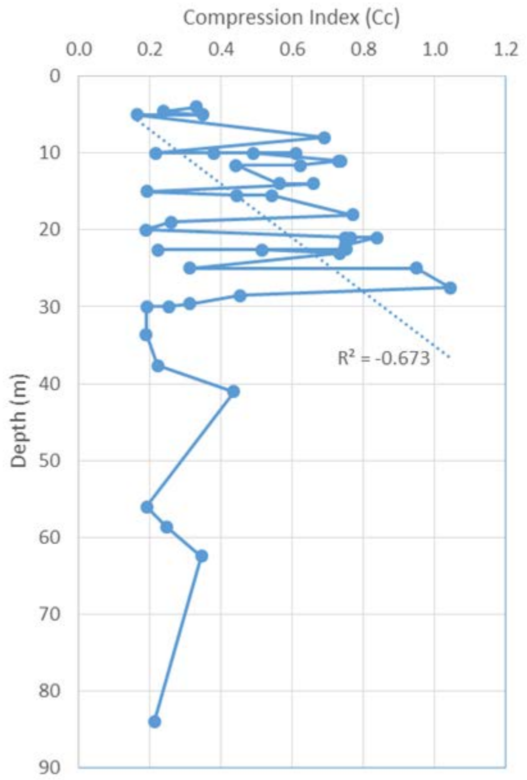

Fig.4 Relationship between Compression Index (Cc) versus depth

From the position of 0.0–30.0 m depth, the value of compression index (C_c) is 0.51 in average and 0.82 as normalized value; meanwhile, the soil deposits more than 30.0 m depth, the compression index (C_c) is considered about 0.26. The following Table 2 is a relationship between the values of compression index (C_c) and depth with a total depth of the compressible clayey soils is assumed until 120 meters.

Based on calculation, potential consolidation settlement of the light structures (i.e. residential, school, office building, hospital, and terminal with built-in 1 floor only) is about 1.42 cm; meanwhile for medium structures (i.e. light manufacturing and warehouse, 2–3 floors of buildings, museum, and library, etc.), those have potential consolidation settlement until 2.90 cm, and for heavy structures (i.e. heavy manufacturing, and warehouse, high-rise building of hotel, apartment, hospital, public offices, etc.), those have potential consolidation settlement about 4.38 cm.

Value of the potential consolidation settlements as abovementioned has contributed to the land subsidence although the most contributing factor of the land subsidence is presumed to come from the excessive groundwater abstraction that directly decreases the presence of voids by time.

Table 2 Compilation of geotechnical parameters for consolidation settlement calculation

Depth	Overburden Pressure before Loading	Pre-consolidation Pressure	Over Consolidation Ratio	Initial Void Ratio	Consolidation Index
D (m)	σ'_0 (kg/cm^2)	σ'_c (kg/cm^2)	OCR -	e_0 -	C_c -
4.00	0.29	0.44	1.52	1.39	0.33
4.60	-	1.00	-	-	0.24
5.00	-	1.26	-	1.26	0.35
5.00	-	-	-	-	0.17
8.00	0.45	0.30	0.67	2.00	0.69
10.00	-		-	-	0.22
10.00	0.62	0.26	0.45	1.68	0.61
10.00	0.72	0.52	0.72	1.18	0.38
10.00	0.97	0.41	0.42	1.32	0.49
11.00	-	1.95	-	1.95	0.73
11.00	-	1.89	-	1.89	0.74
11.60	-	0.33	-	-	0.62
11.60	-	0.75	-	-	0.44
14.00	-	1.72	-	1.72	0.56
14.00	1.17	1.00	0.65	1.53	0.66
15.00	-		-	-	0.19
15.50	-	1.37	-	1.37	0.44
15.50	-	1.27	-	1.27	0.54
18.00	1.31	0.65	0.50	1.81	0.77
19.00	-	1.50	-	-	0.26
20.00	-		-	-	0.19
21.00	-	1.90	-	1.90	0.77
21.00	-	1.97	-	1.97	0.75
21.00	-	1.87	-	1.87	0.84
22.00	1.54	0.60	0.39	1.81	0.75
22.50	-	1.66	-	1.66	0.75
22.60	-	1.25	-	-	0.22
22.60	-	0.40	-	-	0.51
23.00	-	0.55	-	-	0.74
25.00	-	-	-	-	0.31
25.00	1.83	0.60	0.33	2.12	0.95
27.50	-	2.23	-	2.23	1.04
28.50	-	1.29	-	1.29	0.46
29.60	-	1.00	-	-	0.31
30.00	-	1.75	-	-	0.25
30.00	-	-	-	-	0.19
33.60	-	1.50	-	-	0.19
37.60	-	1.00	-	-	0.22
41.00	-	1.00	-	-	0.44
56.00	-	1.75	-	-	0.19
58.60	-	1.50	-	-	0.25
62.40	-	1.50	-	-	0.35
84.00	-	0.85	-	-	0.21

Table 3 Total consolidation settlement of the ground based on occupancy or use

Depth (m)	Occupancy Use	Load Pressure (kPa)	C_c (n/a)	S_c (cm)	Total Settlement (cm)
00 - 30	Residential, School, Office	19.45	0.82	0.73	1.42
30 - 120	Building, Hospital, Terminal (1 Floor)		0.26	0.69	
00 - 30	Light Manufacturing & Warehouse,	43.89	0.82	1.49	2.90
30 - 120	or 2-3 Floors Buildings, Museum, Library		0.26	1.41	
00 - 30	Heavy Manufacturing &	73.4	0.82	2.24	4.38
30 - 120	Warehouse, High-rise Building (Hotel, Apartment, Hospital, Offices)		0.26	2.14	

4. SUMMARY AND RECOMMENDATION

The northern part of Semarang city is mostly dominated by large lowlands and coastal areas formed by Alluvial fan and flood-plain as clayey soils from the thick Quaternary deposits. Typical clayey soils are commonly categorized as normally consolidated clays with consistency soft and easy to be remolded. The compressible behavior of the soils is caused by the presence of voids in the soil structures. Additional surcharge loads due to the growth of the city (i.e. incremental of load stress concentration due to building structures, facilities, and other infrastructures) over the clayey soils have resulted in the generation of excess pore-air and pore-water pressures in which the excess pore-water pressures has dissipated with time.

At Semarang city as referring to the previous discussion, potential consolidation settlement of the light structures (with the surcharge load assumed about 15 kPa) is about 1.42 cm; meanwhile for medium structures (35 kPa) the potential consolidation settlement about 2.90 cm, and for heavy structure (60 kPa) the potential consolidation settlement about 4.38 cm.

It is understood that the values of the consolidation settlements are more predictive and relying on the empiric approach. Some opportunity to developed in the future studies such as installing some geotechnical instruments such as settlement plate, piezometer, a global positioning system (GPS), prism, and other geodetic survey device to monitor ground settlement in place. This approach is expected more effective, accurate, and reliable to provide the actual supporting data as a reference of settlement cross-check as a comparison between theoretical and actual condition. Further, regional planning in Semarang city should be considering the load stress factor, mainly for the northern area.

5. ACKNOWLEDGMENT

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