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Rate of Subsidence Due to Primary Consolidation on Cileles Village, Jatinangor Subdistrict

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Abstract. Jatinangor is an area of education in Sumedang Regency. Because many educational institutions established in this area, Jatinangor had a high level of infrastructure development. Soil plays an important role in determining the security level of infrastructure built on it. Imposition on the surface due to building load can have an impact on land subsidence. This study aims to determine the engineering properties of soil in research area, so that can know the rate of subsidence due to primary consolidation because of building load. The engineering properties of soil obtained from laboratory tests, such as unit weight, moisture content, void ratio, porosity, specific gravity, coefficient of permeability, angle of internal friction, cohesion, preconsolidation pressure, coefficient of consolidation, compression index, and swelling index. Based on the calculation bearing capacity of soil for general shear failure condition with strip footings type, the value of allowable bearing capacity ranges from 0.433 kg/cm2 – 12.064 kg/cm2. Assuming the building load addition is equal to the value of allowable bearing capacity, within 1 year the land subsidence is about 0.43 cm - 11.37 cm.

1. Introduction

Jatinangor was an area of plantation and agriculture. However, since the establishment of Jatinangor as educational areas, plantations converted into residential, industrial center and trading. Jatinangor area changed rapidly with the construction of four universities, namely Institut Koperasi Indonesia (IKOPIN), Universitas Padjadjaran (UNPAD), Sekolah Tinggi Pemerintahan Dalam Negeri (STPDN), and the Universitas Winaya Mukti (UNWIM).

The current Jatinangor environmental conditions degraded due to unplanned development. It can be seen from an irregular residential construction, crowded, and dirty, narrow streets and prone to traffic jam, and the accumulation of garbage. In addition, the high population density of Jatinangor can also exacerbate environmental conditions. Based on Central Bureau of Statistics of Sumedang Regency (2015), the population density of Jatinangor is 4,298 people/km2.

Due to the rapid growth of infrastructure development in the Jatinangor area, it is necessary to hold a better development planning. Soil plays an important role in determining the security level of infrastructure built on it. Excessive development without seeing the technical aspects of soil as an infrastructure support can cause environmental impacts such as land subsidence. Because the building load on the surface, water within the soil pore will be squeezed out, so the soil will compress and the soil surface will decrease as pressure increases. In geotechnical, this phenomenon is known as consolidation. Provision of pressure in a certain period and certain large will affect the magnitude of the decline and speed to land subsidence. Giving pressure on certain periods and certain magnitudes will affect magnitude and duration of land subsidence.

2. Literature Review

Frini (2015) in Geological Map of Jatinangor Area, Sumedang District explained that research area is composed by volcanic rock, specifically lapilli tuff and tuff. This area is part of the foot of Mount Manglayang. Judging from the geomorphology, this area has the form of volcanic hills landform quarter with a gentle slope to steep. Based on its geomorphology, this area has a landspace of quarterly volcanic hills with sloping slope to steep slope.

Figure 1. Location of research area in Cileles Village, Jatinangor Subdistrict, West Java

The material of the crust is broadly divided into two, namely rock and soil. Based on the geological concept according to Hunt (2007), rock is the material of the Earth’s crust, composed of one or more minerals strongly bonded together that are so little altered by weathering that the fabric and the majority of the parent minerals are still present. Soil is a naturally occurring mass of discrete particles or grains, at most lightly bonded together, occurring as a product of rock weathering either in situ or transported, with or without admixtures of organic constituents, in formations with no or only slight lithification.

Soil bearing capacity is the ability of the soil to receive load safely without causing shear failure in the soil depends on soil shear strength. Terzaghi (1948, in Bowles, 1989) popularized the bearing capacity formula calculated into the ultimate bearing capacity (qult). Ultimate bearing capacity is the theoretical maximum pressure which can be supported without failure. Therefore, allowable bearing capacity (qa) must be less than the ultimate bearing capacity. The ultimate bearing capacity is depends on the value of the soil shear strength. Value of the safety factor (F) that is commonly used for the analysis of allowable bearing capacity is 3 to 4 (Das, 1999). Relationship of ultimate bearing capacity, safety factor, and allowable bearing capacity is described in the following equation

$$q_a = \frac{q_{ult}}{F}$$

Terzaghi (1948, in Bowles, 1984) developed his bearing capacity equation for strip foundations by analyzing the forces acting. The equation for the ultimate bearing capacity is

Strip $q_u = (c.N_c + \gamma.D_f.N_q + 0{,}5.\gamma.B.N_\gamma)$

Type of foundations is divided into three, the form of strips (continuous), circular, and square. Terzaghi's bearing capacity equation has been modified for other types of foundations by introducing the shape factors. The equations are

Circular $q_u = (1{,}3.c.N_c + \gamma.D_f.N_q + 0{,}3.\gamma.B.N_\gamma)$
Square $q_u = (1{,}3.c.N_c + \gamma.D_f.N_q + 0{,}4.\gamma.B.N_\gamma)$

Where, qu = ultimate bearing capacity, B = width of the foundations, Df = depth of foundations, γ = unit weight, c = cohesion, Nc,Nq,Nγ = bearing capacity factor, a function of the angle of friction, φ = angle of friction.

The value of bearing capacity generated from Terzaghi equation (Bowles, 1989) is smaller than the value obtained from other researchers. Therefore, the Terzaghi equation is better to used, because it reflects greater anticipation than the others.Referring to the DAS, consolidation is a gradual process of volume reduction in perfectly saturated soils with low permeability due to the partial drainage of pore water. In other words, consolidation is a gradual process of groundwater expulsion because of the load on the ground that occurs as a function of time due to small soil permeability. This process continues until the excess pore water pressure caused by the increase in total pressure has been completely lost. Consolidation may be due to one or more of the following factors: external static loads from structures, self-weight of the soil such as recently placed fills, lowering of the ground water table, desiccation (Murthy, 2002).

Preconsolidation pressure is maximum effective overburden pressure to which the layer has ever been subjected at any time in its history. Preconsolidation pressure is used to determine the normally consolidated condition or overconsolidated condition. Overconsolidation ratio (OCR) is a ratio between preconsolidation pressure (Pc') with present effective vertical pressure (Po). The overconsolidation ratio (OCR) for soil can now be defined as

$$OCR = \frac{P_c'}{P_o}$$

If OCR = 1 (normally consolidated soil), OCR> 1 (overconsolidated soil), OCR <1 (soil is undergoing consolidation). The total compression of a saturated clay strata under excess effective pressure may be considered as the sum of:

a. Immediate compression
b. Primary consolidation
c. Secondary consolidation

Calculation of land subsidence due to primary consolidation is done at each layer of soil. If the thickness of the stratum is too large, the stratum may be divided into layers of smaller thickness not exceeding 3 m. The equation for the total land subsidence due to primary consolidation may be written as

$$S = \sum \left[\frac{C_c H_i}{1 + e_o} log \left(\frac{p_{o(i)} + \Delta p_i}{p_{o(i)}} \right) \right]$$

In overconsolidated soil, if $(P_o + \Delta P) \leq P_c$ then the subsidence becomes

$$S = \frac{C_s H}{1 + e_o} log \frac{p_c}{p_o} + \frac{C_c H}{1 + e_o} log \left(\frac{p_o + \Delta p}{p_c} \right)$$

The time required for consolidation is calculated using

$$T_v = \frac{C_v.T}{H^2}$$

Where, S = primary subsidence, H = layer of thickness, Cc = compression index, Cs = swell index, eo = initial void ratio, po = effective overburden pressure, Δp = increase of effective pressure, pc = preconsolidation pressure, Tv = factor of time is influenced by the degree of consolidation, Cv = coefficient of consolidation, t = certain time.

The values of the time factor and average degrees of consolidation may also be approximated by the following simple relationship

For U = 0 to 60 % $Tv = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$

For U > 60% $Tv = 1{,}781 - 0{,}933\log(100 - U\%)$

Where, U = degree of consolidation

3. Methods

The research started from the preparation through literature study on geotechnical and development of Jatinangor and surrounding area. The next step is to inventory equipment and conduct field surveys. Field survey involves undisturbed soil sampling and description of soil in the research area. Prior to soil sampling, first drilling the ground by hand drill (hand auger) to a certain depth. Sample of undisturbed soil is drawn using a shelby tube by pressing the tube into the ground.

The next is the laboratory test. Soil was tested to obtain data unit weight, moisture content, void ratio, porosity, specific gravity, coefficient of permeability, angle of internal friction, cohesion, preconsolidation pressure, coefficient of consolidation, compression index, and swelling index. The tests are water content test, unit weight test, specific gravity test, triaxial test, and consolidation test. All laboratory tests are adjusted to ASTM (American Testing and Material Standards).

Prediction rate of subsidence due to primary consolidation because of building load is calculated by involving the required variables. The building load applied to the ground is assumed to be equal to the soil bearing capacity.

4. Results and discussion

Soil in the research area is generally the result of weathering tuff rocks. To obtain soil physical and mechanical parameters, a soil investigation was conducted at nine observation points, and taking undisturbed samples at depths between 110-240 cm. The maps and coordinates of the observation location are shown in Figure 2 and Table 1.

Table 1. Location of observation in the research area

Location of Observation	Coordinates		Depth of Sampling (cm)
	Latitude	Longitude	
NYW1	-6,919416	107,760502	200
NYW2	-6,911789	107,759767	110
JTR 6	-6,921164	107,771081	170
JTR 9	-6,910833	107,77083	150
JTR 16	-6,906778	107,763133	125
TA 5	-6,9221975	107,773247	200
TA 6	-6,9190191	107,771472	160
TA 10	-6,9079139	107,7735	120
TA 11	-6,9132374	107,771422	240

On the top, about 0 to 30 cm from the surface, the soil has been overgrown with vegetation and there are organisms living in this soil layer, soil is blackish brown to black, the soil conditions are soft and moist. This soil is organic clay (OH). This part of the soil is top soil layer spread evenly on almost every surface.

In the layer below, soil conditions become harder and have a lighter color. As the deeper the soil texture becomes more rough. When soil sampling, in general the soil is brown to reddish brown, the soil conditions are rather hard and moist, cohesive, with medium to high plasticity, fine-grained soil ominance of the silt-clay particles (MH-CH), in completely weathered conditions due to the material has become the soil but in some places still seen material rock origin. Physical and mechanical properties of soil in the research area is shown in Table 2.

Figure 2. The maps of the observation location in research area.

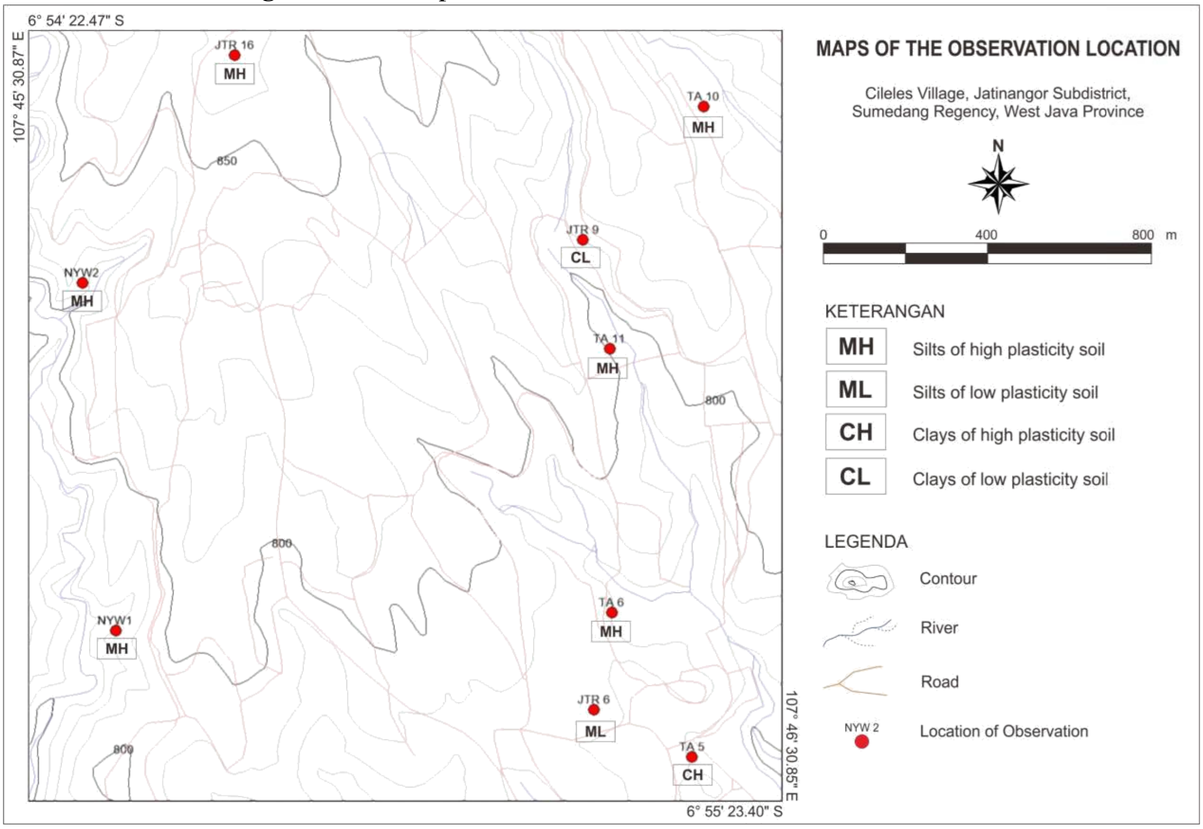

Table 2. Recapitulation of Laboratory Results

Location of Observation	Unit Weight (γ_w) gr/cm^3	Water Content (w) %	Void Ratio (e)	Angle of Friction ( ) o	Cohesion (c) kg/cm^2	Coefficient of Permeability (k) cm/detik	Coefficient of Consolidation (C_v) cm^2/detik	Compression Index (C_c)	Swelling Index (C_s)
NYW1	1,700	45,77	1,227	7,20	1,211	2,25E-07	0,0067339	0,15501	0,0275
NYW2	1,780	36,20	0,945	7,20	4,389	7,80E-08	0,0055409	0,09186	0,0150
JTR 6	1,698	53,15	1,382	7,12	0,210	2,50E-07	0,0079700	0,34000	0,0567
JTR 9	1,626	39,92	1,272	8,89	0,140	2,98E-07	0,0091400	0,25000	0,0417
JTR 16	1,770	30,04	0,945	12,33	0,492	3,71E-07	0,0063294	0,23525	0,0451
TA 5	1,671	32,89	0,735	6,76	0,258	2,50E-07	0,0058500	0,23100	0,0340
TA 6	1,656	40,54	1,199	7,50	0,283	2,03E-07	0,0057200	0,33800	0,0050
TA 10	1,766	36,29	0,812	7,90	0,185	1,69E-07	0,0068900	0,25000	0,0180
TA 11	1,639	50,98	1,385	8,70	0,276	2,39E-07	0,0072000	0,34200	0,0270

The shallow bearing capacity of shallow foundations is obtained from calculations using the Terzaghi equation. The calculations are applied to strip (continuous) foundation type. Based on the literature (Das, 1999), the safety factor used is 3. The calculation of soil bearing capacity is carried out at 1 meter depth and 1 meter wide foundation, under general shear condition. Based on the soil bearing capacity calculations in Table 3, allowable bearing capacity in the research area has variations, between 0.433 to 12.064 kg/cm2.

Table 3. Calculation of bearing capacity in the research area

Location of Observation	Ultimate Bearing Capacity (q_{ult}) kg/cm^2	Allowable Bearing Capacity (q_a) kg/cm^2
NYW1	10,003	3,334
NYW2	36,191	12,064
JTR 6	1,747	0,582
JTR 9	1,300	0,433
JTR 16	5,479	1,826
TA 5	2,098	0,699
TA 6	2,396	0,799
TA 10	1,613	0,538
TA 11	2,502	0,834

Subsidence is one of the technical geological issues. Land subsidence is affected by the engineering properties of the soil or rock constituent. Adding loads to the soil layers can lead to subsidence. The addition of the load can be caused by the building load on it and also due to self-weight of the soil.

Based on the calculation over consolidation ratio (OCR) in Table 4, it is known that the soil is in overconsolidated condition. Over consolidation ratio (OCR) of soil in the research area is greater than 1. This indicates that the effective overburden pressure at this moment is smaller than the pressure experienced by the soil beforehand.

Table 4. *Over consolidation ratio* (ocr) of soil in research area

Location of Observation	Present Effective Vertical Pressure (P_o') kg/cm^2	Preconsolidation Pressure (P_c') kg/cm^2	Over Consolidation Ratio (OCR)
NYW1	0,1704	0,940	5,52
NYW2	0,1871	0,665	3,55
JTR 6	0,1675	0,750	4,48
JTR 9	0,1762	0,780	4,43
JTR 16	0,1771	0,525	2,96
TA 5	0,1930	0,950	4,92
TA 6	0,1850	0,940	5,08
TA 10	0,1920	0,920	4,79
TA 11	0,1880	0,900	4,79

In the calculation, the building load applied to the ground is assumed to be equal to the soil bearing capacity from tehe previous bearing capacity calculation. At each point of observation have different levels of compressibility, so that there is a large variation of land subsidence. The calculation result is shown in Table 5. The time factor used is 90%, so that the time required to achieve the 90% subsidence of the total subsidence due to primary consolidation, as shown in Table 6 If the forecast for the next year, the subsidence can be estimated by the same equation as consolidation time calculation. The subsidence occurring in one year in the research area is 0.43 up to 11.37 cm, can be seen in Table 7. From the results of calculations that have been done, the land subsidence occurred in the research area in one year almost entirely has been reached its total decline of subsidence. This is due to the high compressibility of the soil, with the compression index between 0.09 to 0.34. The higher the compression index will be the greater subsidence that will occur. Soil compressibility can be affected by the water content, the type of minerals in the soil, distribution and uniformity of grains, and the degree of weathering. The more water contained in the soil will be the higher the soil compressibility, and the greater subsidence affected. The water content in the soil is also controlled by the minerals types, such as clay minerals that have high water absorption. Distribution and uniformity of grains will affect the porosity and permeability of the soil. The soil that has many pores and has a continuous pore, will have a high soil compressibility.

5. Conclusion and Recommendation

Soil in the research area is the result of weathering volcanic rocks, that is tuff. This soil is in completely weathered condition. This soil is a fine-grained soil, dominance of the silt-clay particles (MH-CH), with medium to high plasticity. The allowable bearing capacity in the research area ranged from 0.433 to 12.064 kg/cm2 for strip (continous) foundation type in general shear failure conditions. Assuming that the building load is equal to the allowable bearing capacity, land subsidence is 0.43 to 11.37 cm within a year. If observed from the condition, it is necessary to review for land use in this area, such as conducting further analysis on the immediate compression and secondary consolidation to obtain the total land subsidence, soil sampling and testing with closer spacing, do deeper drilling, and the addition information of subsurface conditions. So that the impact of infrastructure development, land subsidence, can be more minimized

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Table 5. Land subsidence due to primary consolidation in research area

Location of Observation	Layer Thickness (H) cm	Overburden Pressure (P_o) gr/cm^2	Increase Of Effective Pressure (ΔP) gr/cm^2	Total Pressure (P_{total}) gr/cm^2	Subsidence (S) cm
NYW1	200	70,80	3334,355	3405,155	10,56
NYW2	110	42,90	12063,605	12106,505	7,39
JTR 6	170	59,33	582,193	641,523	4,18
JTR 9	150	46,95	433,340	480,290	2,78
JTR 16	125	48,12	1826,294	1874,419	11,37
TA 5	200	67,10	699,435	766,535	4,15
TA 6	160	52,48	798,598	851,078	0,44
TA 10	120	45,96	537,625	583,585	1,32
TA 11	240	76,68	834,038	910,718	3,08

Table 6. Time of 90% subsidence each observations locations in the research area

Location of Observation	Layer Thickness (H) cm	Degree of Consolidation (U) %	Factor of Time (Tv)	Time (t) day
NYW1	200	90	0,848	58,30
NYW2	110	90	0,848	21,43
JTR 6	170	90	0,848	35,59
JTR 9	150	90	0,848	24,16
JTR 16	125	90	0,848	24,23
TA 5	200	90	0,848	67,11
TA 6	160	90	0,848	43,93
TA 10	120	90	0,848	20,51
TA 11	240	90	0,848	78,52

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Table 7. Land subsidence in 1 year

Location of Observation	Layer Thickness (H) cm	Factor of Time (Tv)	Degree of Consolidation (U) %	Subsidence (S) cm	Subsidence in 1 Year (S) cm
NYW1	200	5,309	98	10,56	10,35
NYW2	110	14,441	100	7,39	7,39
JTR 6	170	8,697	100	4,18	4,18
JTR 9	150	12,811	100	2,78	2,78
JTR 16	125	12,775	100	11,37	11,37
TA 5	200	4,612	98	4,15	4,06
TA 6	160	7,046	98	0,44	0,43
TA 10	120	15,089	100	1,32	1,32
TA 11	240	3,942	98	3,08	3,02

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