Study of Clay Soil Improvement with Well-Graded Sand on Clay Soil Consolidation Parameters

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Abstract. Soil plays a vital role in supporting infrastructure. Clay soils deform under loads due to their high plasticity. Consolidation of the settling that occurs in clay soil takes an extended period because of their low permeability. The Palembapang area in Umbul Lioh, South Lampung faces the issue of low bearing capacity and road settlement. The study conducted soil improvement by mixing well-graded sand. The objective is to assess compression index (C_c), compression coefficient (a_v), coefficient of volume change (m_v), consolidation coefficient (c_v), and consolidation settlement (S_c) parameters for soil stabilized with well-graded materials. Different additions of 4%, 8%, 10%, 12%, and 16% were tested. The clay in our test is classified as A-7-5 (AASHTO) and OH (USCS). The addition of sand resulted in a decrease in the optimum moisture content value but an increase in the dry volume weight value during the compaction test. In the consolidation test, the addition of sand led to a decrease in the values of compression index (C_c), compression coefficient (a_v), coefficient of volume change (m_v), and consolidation settlement (S_c), but an increase in the value of consolidation coefficient (c_v).

Keywords: Clay Soil, Soil Improvement, Sand, Consolidation.

1 Introduction

Soil serves as a foundation for the structural stability of construction. When soil sustains a load, it undergoes settlement, resulting in decreased support. This disparity in settlement can cause instability in the construction [1]. The settlement that occurs will take a long time. Soils with high expansiveness undergo changes in volume when moisture levels change [2]. The compressibility behavior displayed by fine-grained soils is classified according to the deposit stress and whether they are normally consolidated or over-consolidated [3].

Clay soil contains fine particles, which allow it to retain high levels of water and make drainage challenging [1]. Sand grains are larger than those of clay. Combining sand with clay soil can result in soil improvement known as regradation [4]. The distinction between sand and clay lies in their deposition. Settlement on clay surpasses that of sand [5].

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According to [3] Mixing fine sand with variations of 10%, 20%, 30%, 40%, 50%, 60%, and 80% demonstrated a reduction in compression index, swelling index, volume compressibility coefficient, and swelling potential. The addition of fine sand presents an effective method of regulating the behavior of clay soil.

Research conducted to [6] indicates that the soil from Umbul Lioh, Palembapang, Kalianda, belongs to the soft clay category. The soil's liquid limit is 71.22%, and its plasticity index is 48.4%. Previous research has not attempted to enhance this soft clay soil by incorporating materials with well-graded properties.

2 Literature Review

2.1 Clay Soil

Clay is a fine-grained soil type that has a high concentration of clay. The diameter of clay particles is less than 0.002mm [6]. Clay soils have unfavorable characteristics such as low bearing capacity, significant volumetric changes due to swelling, and high shrinkage rates [7]. Clay has a high degree of plasticity, which can compromise the integrity of the structure above it, and such characteristics pose a potential hazard to any building constructed on top of it. Clays with elevated plasticity typically have a high water content [8].

2.2 Soil Improvement

Soil improvement is used to improve the technical properties of the soil, including its permeability, its bearing capacity, and its potential for shrinkage [8]. Soil improvement can be achieved through the use of additives, regradation, or dewatering methods. Re-grading involves mixing a stabilizing material, such as sand or gravel, into the soil to create a more stable soil layer [4].

2.3 Sand

Sand is considered a non-cohesive type of soil that exhibits high permeability [9]. The sand's high permeability facilitates water penetration, while under deformation, it reacts to the load by obstructing the pores. Sand typically has a grain size ranging from 0.006 to 2 mm [10]. Based on the Unified Soil Clasification System classification, good sand has the following criteria $1 < C_c < 3$ and $C_u > 6$.

2.4 Consolidation

Consolidation is the process of volume reduction due to loading and is influenced by the rate of water escape from the soil voids. Saturated soil, which has low permeability under load, increases the pore water pressure in the soil [6].

The compression index value is used to determine the amount of compression. The compression index is the slope of the straight-line portion of the *e-log p’* graph.

$$C_c = \frac{\Delta e}{\Delta \log p'} = \frac{e_1 - e_2}{\log p_2' - \log p_1'} = \frac{e_1 - e_2}{\log(p_2'/p_1')} \quad (1)$$

The compression coefficient is the coefficient of change in void ratio per unit change in stress or the slope of the curve of void ratio (e) and effective stress (p').

$$a_v = \frac{\Delta e}{\Delta p} = \frac{e_1 - e_2}{p_2' - p_1'} \quad (2)$$

The coefficient of volume change expresses the ratio of volume change per unit increase in effective stress expressed in terms of thickness or void ratio.

$$m_v = \frac{a_v}{1 + e_1} \quad (3)$$

The rate of consolidation settlement is calculated with the consolidation coefficient using the square root method.

$$c_v = \frac{0.848 H_t^2}{t_{90}} \quad (4)$$

The total consolidation settlement using the *e-log p* graph is expressed in equation 5, for normally consolidated clays it is expressed in equation 6.

$$S_c = \frac{e_0 - e_1}{1 + e_0} H = \frac{\Delta e}{1 + e_0} H \quad (5)$$

$$S_c = C_c \frac{H}{1 + e_0} \log \frac{p_1'}{p_0^1} \quad (6)$$

3 Method

The research was conducted at the Soil Mechanics Laboratory, Department of Civil Engineering, Faculty of Engineering, University of Lampung. The clay soil samples used in this study came from Dusun 3 Umbul Lioh area, Palembapang Village, Kalianda District, South Lampung Regency. The sand used came from Gunung Sugih.

The tests include physical and mechanical properties. Physical property tests conducted were analysis of water content, specific gravity, sieve analysis, and determination of Atterberg limits. Mechanical tests included proctor and consolidation tests. The sand was manually mixed and re-tested for physical properties. After mixing, proctor compaction was performed to obtain the optimum moisture content (OMC) value for each percentage of the mix composition. After the compaction, a consolidation test was carried out.

4 Results and Discussion

The results of the tests carried out provide physical and mechanical properties of the addition of well-graded sand with variations of 4%, 8%, 10%, 12% and 16%.

4.1 Physical Properties Tests

The physical properties tests that have been carried out in the laboratory can be seen in table 1. The addition of sand affects the value of physical properties. In the case of the water content test, there is a significant decrease. This difference in test conditions is due to interruption of mixed clay test. The samples were dried in the sun and exposed to wind, resulting in a decrease of their moisture content. Specific gravity in the addition of sand increases, but when compared to the specific gravity of the original soil it decreases. Liquid limit and plasticity index decreased with the addition of sand.

Table 1. Soil identification test result.

Variation (%)	Water Content (%)	Specific Gravity (gr/cm^3)	Liquid Limit (%)	Plasticity Index (%)	Finer # 200 (%)
0	51.75	2.59	78.41	42.56	54.61
4	10.66	2.45	76.78	42.20	52.42
8	11.47	2.48	72.74	41.49	51.83
10	8.65	2.50	72.12	41.27	51.30
12	7.09	2.52	67.98	39.65	50.86
16	7.14	2.53	60.89	33.35	50.28

4.2 Soil Compaction Test

The addition of sand resulted in an increase in dry bulk density and a decrease in optimum moisture content are shown in table 2. The optimum moisture content was used to make consolidation test specimens.

Table 2. Soil compaction test results.

Variation (%)	Optimum Moisture Content (%)	Dry Volume Weight (gr/cm^3)
0	34.50	1.205
4	34.60	1.200
8	32.10	1.260
10	28.70	1.305
12	27.00	1.325
16	24.80	1.345

According to [3] The results show that fine sand with variations of 10%, 20%, 30%, 40%, 50%, 60%, and 80% can increase the dry volume weight and decrease the optimum moisture content. The increase in dry bulk density occurs due to shrinkage of pore volume. In addition, the absorptive capacity of the original soil is reduced due to the mixing of graded materials.

4.3 Consolidation Test

The results of the consolidation tests carried out are shown in table 3. The addition of sand affects the values of the consolidation parameters. The tests were carried out by adding loads of 50 kN/m^2, 100 kN/m^2, 200 kN/m^2, 400 kN/m^2 and 800 kN/m^2. After adding the load, the load was reduced to 50 kN/m^2.

Table 3. Consolidation test results.

Variation (%)	C_c	c_v (cm^2/s)	a_v (m^2/kN)	m_v (m^2/kN)	S_c (cm)
0	0.7703	0.00020	0.0720	0.0338	0.2025
4	0.4665	0.00023	0.0706	0.0331	0.1950
8	0.4086	0.00039	0.0489	0.0234	0.1526
10	0.3926	0.00041	0.0467	0.0230	0.1491
12	0.3401	0.00056	0.0453	0.0215	0.1255
16	0.3209	0.00059	0.0395	0.0210	0.1227

The compression index results based on the test decreased when sand was added, as shown in Fig/ 1. The value of compression index in the original soil was 0.7703 to 0.3209 in the addition of 16% sand. Sand particles are coarser and larger than clay particles. Smaller clay particles cause the soil to be easily compacted so that it decreases. If the compression index value is low, the settlement potential is reduced.

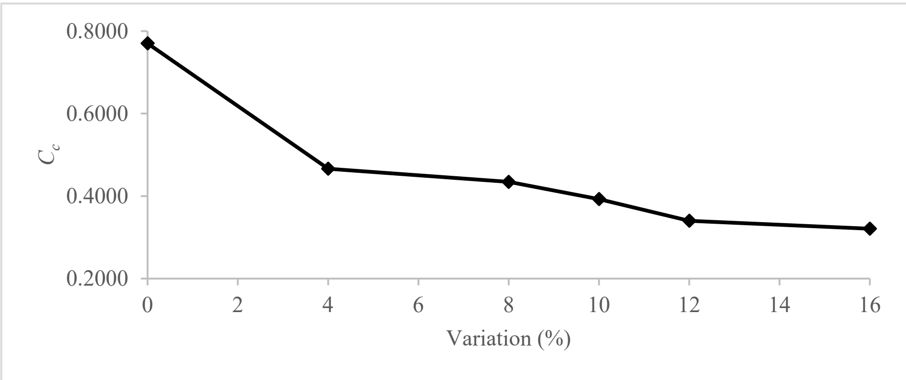

Fig. 1. Relation sand and C_c.

Research by [3] shows that the increase of fine sand decreases the value of the compression index because the content of clay soil decreases, so it becomes less plastic, the shrinkage potential experienced decreases and the compressibility characteristics disappear.

The results of the consolidation coefficient based on the test increased when sand was added, as shown in Fig. 2. The value of the coefficient of consolidation in the original soil was 0.00020 cm^2/s to 0.00059 cm^2/s with the addition of 16% sand. The changes that occur in the coefficient of consolidation indicate the acceleration of the consolidation process.

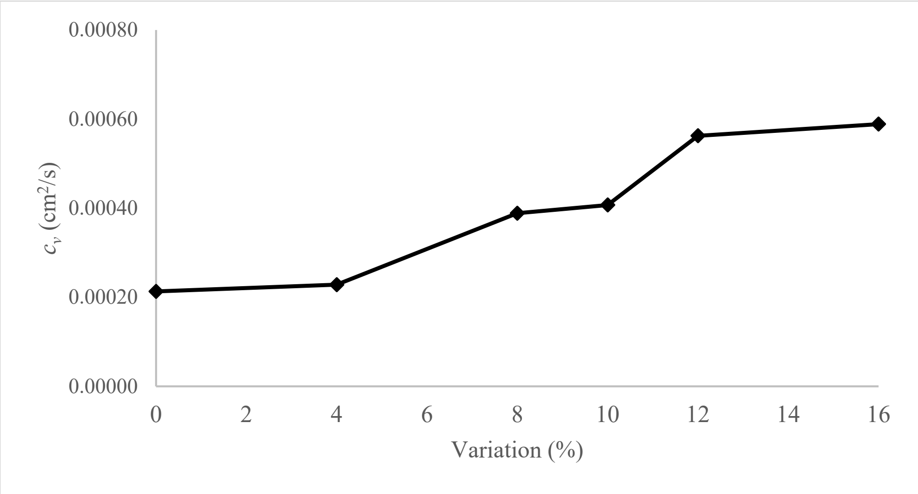

Fig. 2. Relation sand and c_v.

Research by [11] showed that increasing construction and demolition waste (CDW) up to 40% gradually affected the consolidation rate, thus increasing the consolidation coefficient. CDW in clay soil helps to drain water and settle in a faster time.

The compression coefficient has decreased from the original soil value of 0.0720 m^2/kN to 0.0395 m^2/kN with the addition of 16% sand, as shown in Fig. 3. The compression coefficient is a parameter used to measure the rate of change of soil volume when a load is applied. The addition of sand reduces the compression of the clay soil and results in a slow change in volume when a load is applied. According to [10] the addition of sand material will cause the value of the compression coefficient to decrease until the maximum addition of sand is 30%.

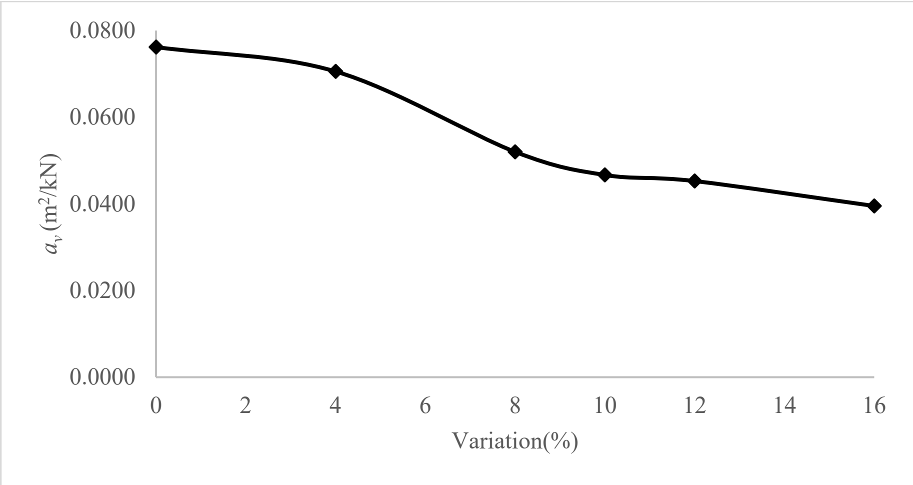

Fig. 3. Relation sand and a_v.

Volume change coefficient is defined as the ratio of volume change to effective stress increment. The coefficient of volume change is used as a parameter to measure the change in soil volume when a load is applied. In this study, the volume change decreased from an initial value of 0.0338 m^2/kN to 0.0210 m^2/kN with the addition of 16% sand, as shown in Fig. 4. Research by [3] mixing fine sand gives a value for the coefficient of volume change that decreases up to a maximum addition of 80% sand.

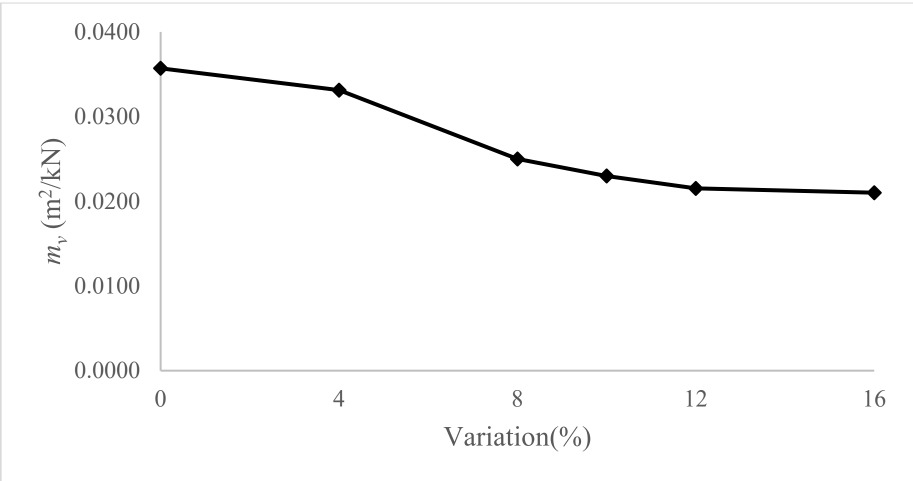

Fig. 4. Relation sand and m_v.

Consolidation settlement represents the change in volume of a soil due to loading during the consolidation process. In this study, the addition of sand up to 16% was able to reduce the decrease in consolidation, as shown in Fig. 5. In this study, the initial consolidation decreases of 0.2025 cm decreased to 0.1227 cm up to the addition of 16% sand. This is due to the rapid escape of water through the pores of the soil due to the mixing of sand particles with clay particles. According to [1] stabilized clay with cement up to 12% variation and experienced a decrease in consolidation.

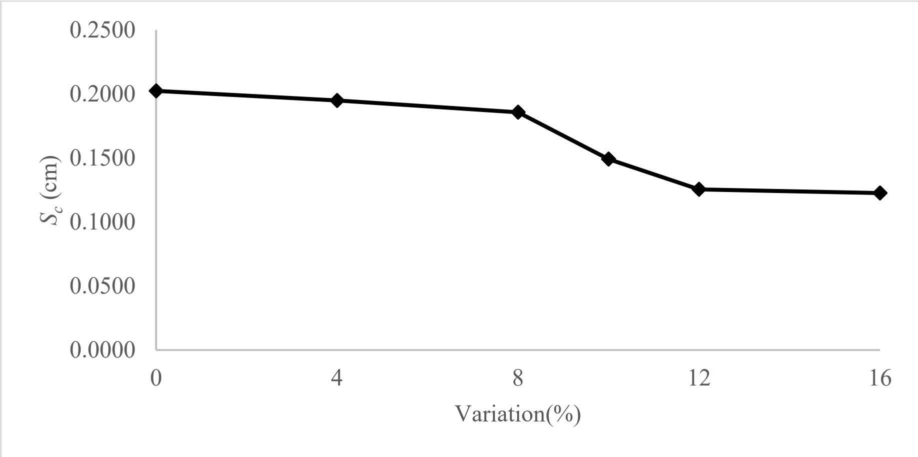

Fig. 5. Relation sand and S_c.

A decrease in void ratio occurs when sand is added, as shown in Fig. 6. Larger sand particles reduce the volume of pores in the soil as they are filled by sand. The application of load during the consolidation test causes a decrease in pore volume and further compaction. It was determined that the compressibility of the material varies with different void ratios. As the effective stress increases, the void ratio decreases, and the model accurately represents the graph's behavior under zero effective stress.

[12] The author describes the trend of decreasing maximum and minimum void ratios in silty sand as the fines content increases. As the proportion of fines in a loose or dense sand matrix increases, the majority of fine particles initially occupy the voids between the sand particles. This indicates a decrease in the void ratio with an increase in the fines content.

The void ratio of the clay soil matrix exceeds that which could be attained in the absence of sand. This indicates that, on average, the clay particles are not in contact, and the mechanical characteristics are influenced not only by the clay soil matrix but also by the sand particles.

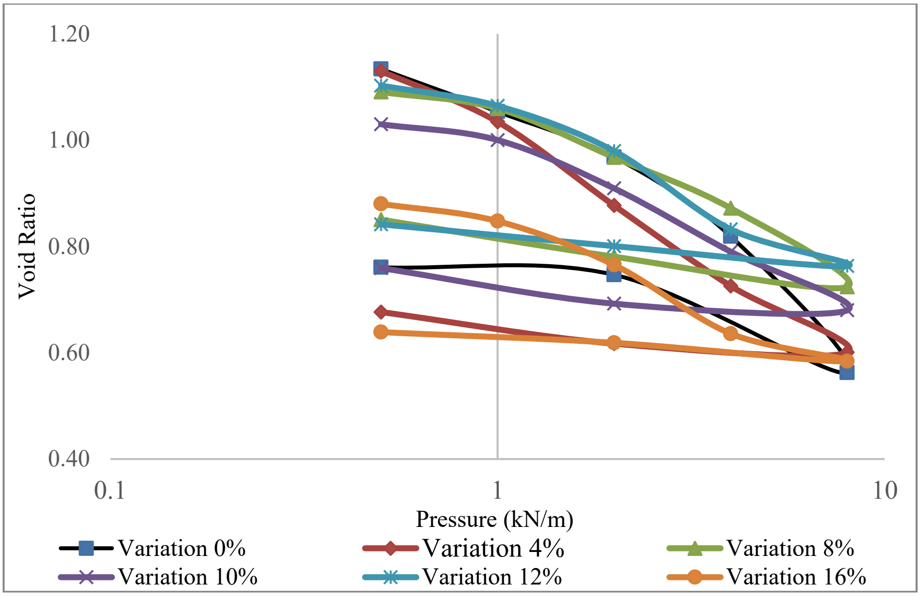

Fig. 6. Relation void ration and pressure.

5 Conclusion

The results of adding sand as a well-graded material with variations of 4%, 8%, 10%, 12% and 16% reduce the value of the compression index, compression coefficient, volume change and decrease in consolidation. For the value of the coefficient of consolidation has increased.

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