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Geotechnical behaviour of soft soil in East Java, Indonesia

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Abstract. Currently, the construction of road infrastructure in all regions of Indonesia is highly encouraged, including free roads that connect between provinces. In some parts of the area in East Java, the free roads pass through regions with soft clay so that special treatment is needed. A geological and geotechnical analysis of the nature of the soft soil needs to be conducted to determine the methodology of reducing the compressibility of the soft soil. Based on geological analysis, soft soil is a sedimentation product of the Pliocene – Holocene era. This soil is generally fine-grained, with a high natural water content, and a large amount of organic matter. Several laboratory experiments determined that the soft soil was classified as high plasticity silt with SPT value less than 10 and reached down to a depth of 15.5 m. The value of the undrained cohesion of the soil is around 24.7 kN /m² dependent on the conditions of water content. Estimation of primary consolidation settlement is 2.24m in 18 years. In the soaked-unsoaked CBR experiment, the water content of 37.7% is the residual water content, which is the lowest CBR.

1. Introduction

A structure that is built on soft soil may suffer from instability, such as a collapse. The instability may occur, before the structure is built, or even with a completed structure like a road, due to environmental changes related to natural influences, so that the structure becomes easily damaged. The condition will require continuous improvement at large costs if the subgrade is not treated.

Several studies, in different countries, have researched the characteristics of soft soil in Tunis [1], Egypt [2], Malaysia [3] and Indonesia [4]. Researchers have used various methods to stabilize soft soil, such as with lime [2, 5] and cement [2, 6]. In another example, the additives were used in grouting [7] and deep soil mixing [8, 9]. Besides using additives, soil improvement can also be done using PVD/Prefabricated Vertical Drain [4, 8, 10, 11] and a combination of PVD and DCM (Deep Cement Mixing) [12].

The purpose of this study is to determine the geological and geotechnical characteristics of soft soil in the north of East Java so that several alternative improvements can be recommended.

2. Geological condition of East Java

One of the geotechnical problems encountered in the construction of transportation infrastructure in the East Java Province, Indonesia, is widespread expansive soil, and soft soil (figure 1).





Figure 1. Map of the spread of soft soil and expansive soil in East Java Province, Indonesia.

The soft soil is the sedimentation product of the Bengawan Solo and Brantas rivers and also occurs in the wetlands. The sedimentation process took place during the Pliocene – Holocene era. This soil is generally fine-grained, has a high natural water content, and contains a large amount of organic matter. The thickness of the young soft sedimentation soil can reach a depth of 40 m [13]. This sedimentary soil generally has a high compressibility and a low load bearing capacity,

The second type of expansive soil is the product of the weathering process of mudstone (residual soil) of the Lidah formation. The Lidah formation is composed of blue-grey mudstone with lenses of carbonates, sandstones and limestone. This geological formation was formed in a shallow marine environment during the Pliocene – Pleistocene era [14]. This residual soil type generally has high shrink-swell characteristics and a low bearing capacity, because of its high content of montmorillonite minerals. The expansive residual soil can cause cracks in the floor of buildings and roads.

3. Site location

This research was carried out in the village of Kedaung Kulon, Grati Subdistrict, Pasuruan Regency, East Java Province, Indonesia. The Indonesian government has built a Gempol – Pasuruan toll road, a road that passes through the area connecting the Gempol area, Sidoarjo, with the city of Pasuruan. The distance between Gempol - Pasuruan has divided into 3 sections, namely, section 1 Gempol - Rembang (13.90 km), section 2 Rembang - Pasuruan (6.6 km), and section 3 Pasuruan - Grati (13.65 km) as seen in figure 2.



Figure 2. Location of study.

4. Result and discussion

4.1. Soil investigation

Based on the SPT (Standard Penetration Test) data, it was found that up to a depth of 11 m, the SPT value of less than 1 showed that the layer was classified as very soft soil. Especially in Sta 31+150 (Kedaung Wetan area), soft soil are around 11-15 m dept. The free road will be built on an embankment that has varying heights above the soft soils which have low carrying capacity which will affect its stability. The instability of embankments can cause landslides or road damage due to differential settlement.

For the soil sample, experiments were conducted to determine the physical properties, flow properties, incompressible properties and mechanical properties of the soft soil.

4.2. Laboratory tests

Laboratory experiments conducted on samples showed that the soil was a high plasticity silt soil. The results of the granular analysis showed that the percentage of distribution passing the 0.074 mm (#200) sieve of 92.25%, which shows fine-grained soil with an Atterberg Limit as follows: liquid limit of 56.12%, plastic limit of 43.36%, shrinkage limit of 11.863%, such that the soil has a plasticity index of 12.76%. Based of USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Official Soil Classification System), soil is classified as silt with low plasticity. The laboratory tests showed a saturated density of 17.21 kN/m³ and a permeability coefficient of 0.0003786 cm/s which indicates the type of silt soil characteristics. The compaction experiments carried out on the soil produced a maximum dry weight of 12.467 kN/m³ with an optimum water content of 31%.

4.2.1. Consolidation Settlement. The dominant characteristic in soft soil is high compression where the load transfer on the ground causes settlement. The settlement due to consolidation primer is a case that must be resolved before the upper structure is established. The consolidation experiment produced a consolidation coefficient and a compression coefficient of, $C_v = 0.001 \text{ cm}^2/\text{dt}$ and $C_c = 0.445$, respectively.

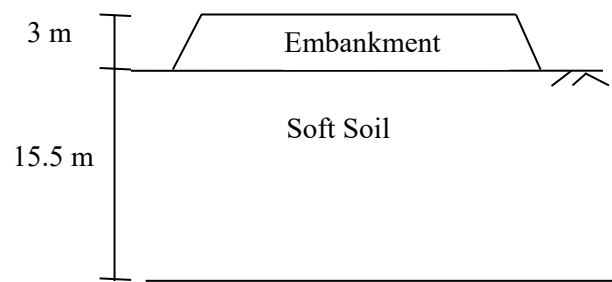


Figure 3. The soil profile of embankment.

Based on the one-dimensional consolidation calculation of the Terzaghi theory, the primary consolidation settlement that should occur is 2.24 m, over 18 years. Soil does not show any indication of swell and shrink (swell potential = 0.8%). Undisturbed sample indicate moisture content of 50.5% which is a plastic phase with a degree of saturation of 94%. If the soil is compacted at optimum water content (OMC) of 31%, the maximum dry density of 12.5 kN/m³.

4.2.2. Effect of water content on soil strength. Analysis of the following soil shear strength parameters will be carried out in the range of field water content and optimum water content. Table 1 shows the experimental results of unconfined compressive strength carried out under undisturbed and OMC conditions.

Table 1. Result of unconfined compressive strength in undisturbed and remoulded sample.

No.	Sample	Moisture Content (%)	qu (kN/m ²)	Cu (kN/m ²)
1	Undisturbed	50,5	49.4	24.7
2	OMC (<i>remolded</i>)	31,2	200.5	100

Based on table 1 it can be seen that the decrease in water content from the undisturbed condition to the OMC condition, significantly increases the soil shear strength. Figure 4 shows that the influence of water is very large on the soil shear strength in undrained condition.

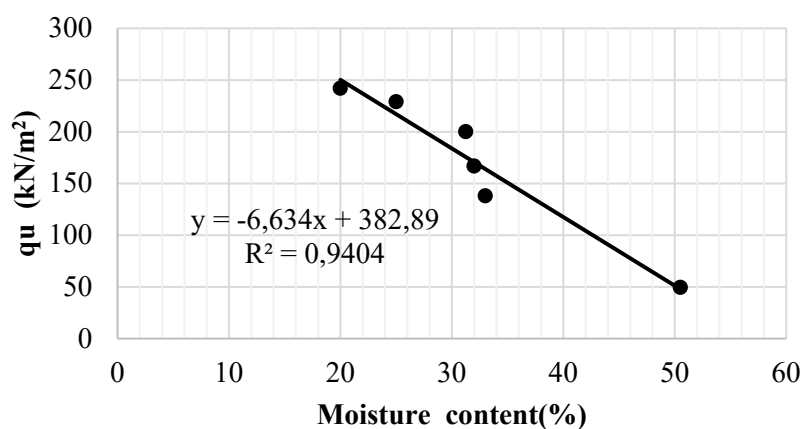


Figure 4. Change in undrained shear strength compare to the moisture content of soil.

Figure 5 shows the stress strain of sample with the different moisture content. It is note that the failure strain generally increase with increasing water content. Soft soil with water content smaller than optimum water content (OMC) tends to be stiffer.

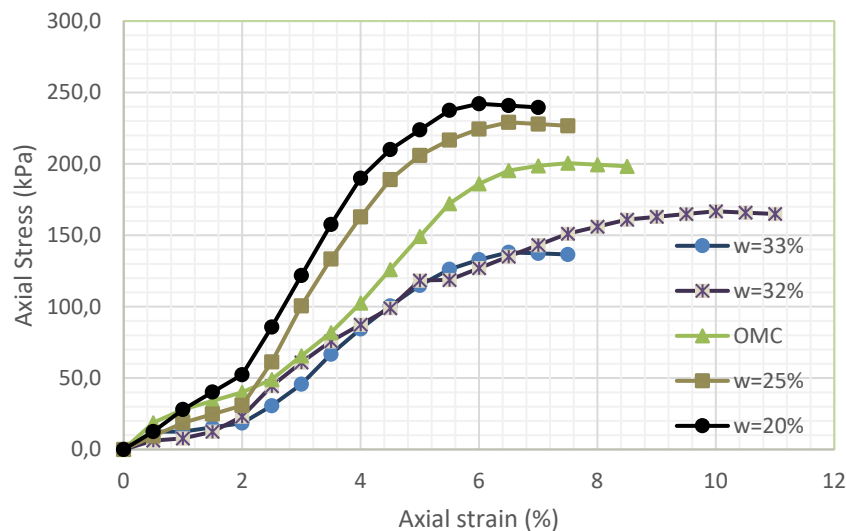


Figure 5. Influence of moisture content to stress strain relation.

In this study, it will also investigate changes in carrying capacity using the CBR test in un-submerged and submerged conditions. The results of CBR experiments can be seen in figure 6. It can be seen that with increasing water content in un-soaked soil, the CBR will decrease up to a level of 38% of moisture. This is inversely proportional to soaked CBR where the water content exposure increases the CBR up to the un-soaked CBR value.

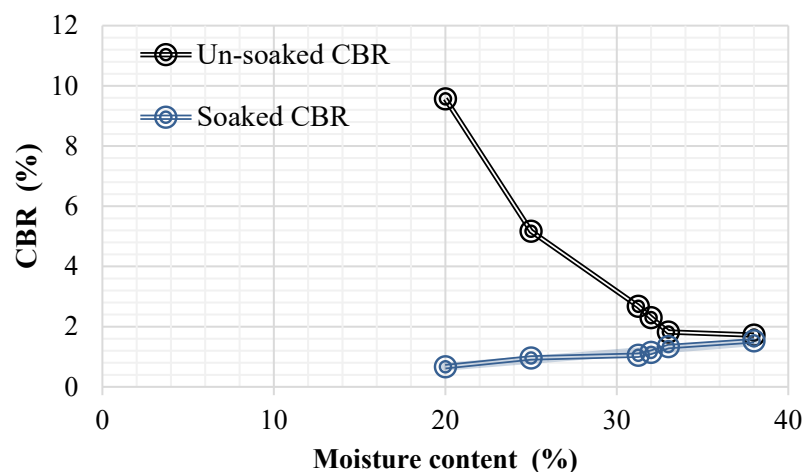


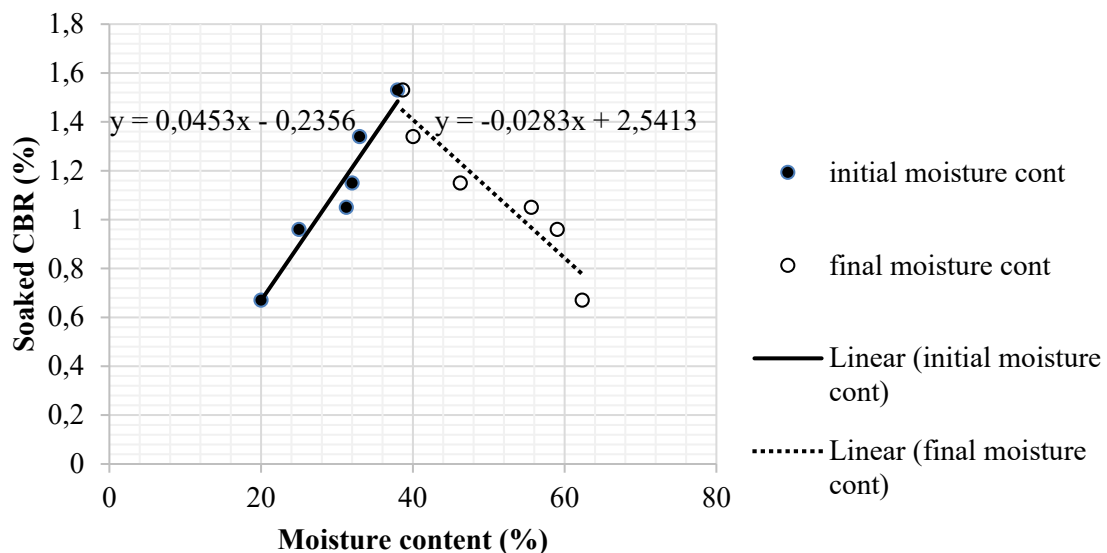
Figure 6. Un-soaked and Soaked CBR in various moisture contents.

In the soaked CBR experiment, water content was checked before and after submersion. Experimental data can be seen in table 2 which shows that at the initial low water content, it produces a high water content after submersion. However, at the initial water content of around 37.7%, soaking does not change the water content much.

Table 2. Initial and Final Moisture Content of Soaked CBR Test.

No	Initial Moisture Content (%)	Soaked CBR (%)	Final Moisture Content (%)
1	20	0.67	62.3
2	25	0.96	59.0
3	31.2	1.05	55.6
4	32	1.15	46.3
5	33	1.34	40.0
6	38	1.53	38.6

If the initial and final moisture content conditions in the soaked and un-soaked CBR are plotted, as shown in figure 7.

**Figure 7.** Regression line analysis of the initial and final moisture content of the CBR.

The regression equation between water content and soaked CBR at the initial water content is:

$$CBR_{\text{soaked}} = 0.0453 \omega - 0.2356 \quad (1)$$

And at the final water content

$$CBR_{\text{soaked}} = -0.0283 \omega - 2.5413 \quad (2)$$

The cutoff point of the two regression equations is the water content of 37.7%.

5. Conclusion

Soft soil on the north coast of East Java is a type of high plasticity silt with a large thickness such that any structural planning requires the initial stabilization of the subgrade layer to reduce compressibility and increase soil strength. Changes in environmental conditions cause changes in the soil water content that affect the strength parameters. The strength of soil sample decreased with an increase in water content. Stress strain relationship is safer in optimum water content rather than other moisture content.

The un-soaked CBR also experiences a phenomenon of decreasing with a low water content compared to optimum conditions and is inversely proportional to the soaked CBR. If the initial water content of soaking is smaller in the CBR, then the water content after soaking will increase until the moisture content approaches a water content of 37.7%, then there is no change after submersion.

Soft soil can be improved by mixing with additives or using PVD to accelerate the consolidation. Further research is required to produce more optimal results.

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