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Assessment to Mechanical Material Properties of Natural and Metakaolin based Geopolymer Stabilized Soil

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Abstract. This study discussed the mechanical properties of natural and metakaolin based geopolymer stabilized soil. The mechanical soil properties is an important soil properties that determine the soil strength parameter and its behaviour. It is proposed to do an assessment on 2 types of soil: natural (remolded) soil and metakaolin based geopolymer (MKG) stabilised soil of Bengawan Solo River Embankment soil. The soil sample are treated on oedometer test in order to know soil compressibility and permeability. The result shows that the implication of MKG for natural (remolded) soil only have an influence in reducing swelling. Also for the permeability, it is found that despite the high porosity (index high vacuum), its permeability is smaller than the permeability of other mixtures.

1. Introduction

Initially, the existing soil embankment of Bengawan Solo River continuously experienced an erosion, so an artificial embankment was built to protect the village from flooding. In order to upgrading this protection, sediment was removed from the riverbed and spread on top of the existing embankment to dry. This soil material was compacted in 40 cm using light compaction plant to a dry density 80% - 85% of the standard proctor optimum, on the dry side of optimum [1]. The soil type along Bengawan Solo River is dominated by the alluvium sediment soil which is in the form of silty soil. The silty soil known as soft soil which has low shear strength and is vulnerable to water content changes.

It is proposed the chemical stabilization to improve the physical and mechanical soil properties. Chemical stabilisation usually occupies lime, Ordinary Portland Cement (OPC), and fly ash to increase the soil solid grain volume with the chemical reaction between stabilizer and soils. However, the utilisation of OPC, lime, etc. are energy intensive and emit large quantity of CO_2. Geopolymer as a soil stabilizer has a high strength, low energy consumption, low cost, excellent adhesion to aggregates, and low CO2 emissions during synthesis [2]. [3] and [4] also stated that polymer has lower shrinkage volume than OPC, and more mechanical strength with short setting time. Hence, the utilisation of geopolymer (in this case is metakaolin based geopolymer, MKG) as a next-generation of soil stabilizers besides the traditional stabilizers offers an effective yet promising alternative [2].

For further analysis on soil strength and behaviour of natural and treated soils, this research studied the experimental study of mechanical soil properties such as compressibility and permeability derived from oedometer test.

2. Material Properties and Experimental Methods

2.1. Material Properties

The soil material for this research derived from the surficial soil (-0.50 m from original ground level) of Bengawan Solo river embankment. The soil fraction dried in an open air and sieved (No. 40) with soil properties shown in Table 1.

Table 1. Natural soil properties.

Physical Properties	Cassagrande	Fall Cone
Liquid Limit (w_L, %)	44.05	45.50
Plasticity Limit (w_P, %)	24.62	17.00
Plasticity Index (IP)	19.43	28.50
G_s	2.69	
Shinkage Limit (w_{SL}, %)	16.45	
Granulometry		
Clay (%)	45.2	
Silt (%)	44.33	
Sand (%)	10.47	
Gravel (%)	0	

The soil which passed sieve no. 40 (425 μm) is classified as inorganic clays of low to medium plasticity, silty slay (CL) according to Unified Soil Classification System (USCS). Some basic properties are shown in Table 1.

2.2. Experimental Methods

The oedometer test was designed to determine compressibility soil subject to a vertical load as well as determine the preconsolidation pressure. It consists in subjecting the sample to a series charges applied and to measure soil compaction over time in each of these charges. Soil samples are placed inside a rigid cylindrical mold with a diameter D = 50 mm with no radial deformation loading $\varepsilon_2 = \varepsilon_3 = 0$. The test is deducted in a dimensionally stable cell and greased and placed between two stones porous to allow water to flow, the load is applied in steps, the compressive loads is exerted vertically on the specimen size D = 50 mm, h = 20 mm below a piston. The deformation is recorded by reading a displacement sensor or a dial hence the time versus displacement curves could be plotted in real time. The materials were prepared initially in slurry state $w_i = 1.5\ w_L$ and settled for 24 hours before it is remolded into the cell to ensure the homogenization. After that, the materials were settled for 24 hours after remolded under the piston. The piston acted as a preconsolidation load which has the mass of 2.7 kPa.

3. Soil Behaviour – Results

3.1. Compressibility

The comparison of natural (remoulded) soil (B.Solo) and MKG Treated Soil (B.Soil_Tr (MKG)) could be seen in Figure 1. The compression curve of MKG Treated Soil tend to have the same pattern as natural (remoulded) soil with bigger value of compression index (C_c). Opposed to the value of swelling index (C_s) which is decreased. The trend shows that the implementation of MKG have a major influence in reducing the swelling.

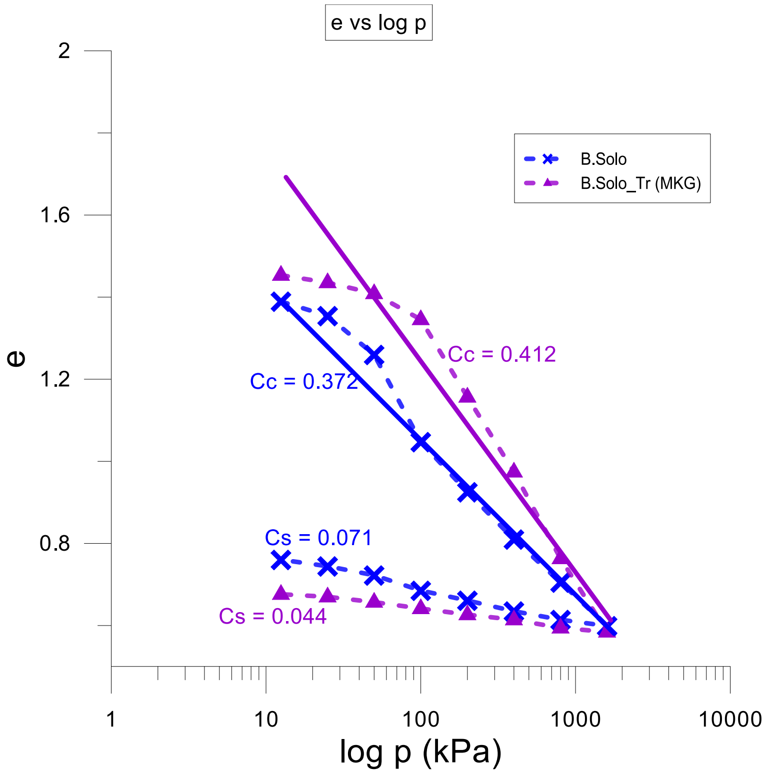

Figure 1. Oedometer path of natural (remolded) soil (B.Solo) and MKG treated soil (B.solo_Tr (MKG)).

For natural remoulded soil, the result shown in the Fig 1. The value of Cc = 0.372 and the swelling index is 0.071 with the ratio of Cc / Cs = 5.2. The curve in Fig 1. is tend to bend after 100 kPa. The bend is followed by two tendencies; first, for low stress domain of remoulded Bengawan Solo soil samples (σ'_v = 12.5 kPa – 100 kPa) shows ideal curve. It expresses a process of progressive degradation of the cementation between the grains. Second, after the sample reached high stress domain $\sigma'_v > 100$ kPa, the curve changes drastically and gives a high value of compression index. It corresponds to a cementation breaking between grains of material. The soil sample observed by Scanner Electron Microscopic (SEM) in order to convince the grain structure of soil in powder form (Figure 2.).

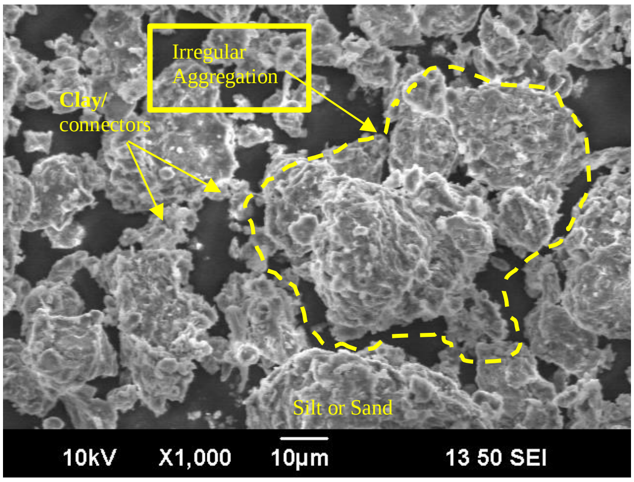

Figure 2. SEM Images of natural soil in powder form (the magnification 1000x).

3.2. Coefficient of Consolidation and Permeability

From oedometer test, we could draw the deformation vertical vs square time curve. Casagrande method is applied to determine t_{50} and t_{100}, and the method of Taylor to determine t_{90}. The coefficient of consolidation is defined by the equation:

$$C_v = \frac{T_v d^2}{t} \quad (1)$$

Where T_V is a time factor depending on degree of consolidation, t is the time required to achieve the degree consolidation and d is the distance of drainage, in this test it is equal to half the thickness the sample because the drain is allowed to both sides.

When oedometer test, coefficient of consolidation, C_v, can be determined by the Casagrande method or the method of Taylor. This study presents two methods, first is the method of Taylor (eq. 2.) and second is the method of Casagrande (eq. 3).

(Taylor Method) $$C_v = \frac{0.848 d^2}{t_{90}} \quad (2)$$

(Casagrande Method) $$C_v = \frac{0.197 d^2}{t_{50}} \quad (3)$$

where t_{90} and t_{50} are the times needed to achieve a degree of consolidation of 90% and 50% respectively.

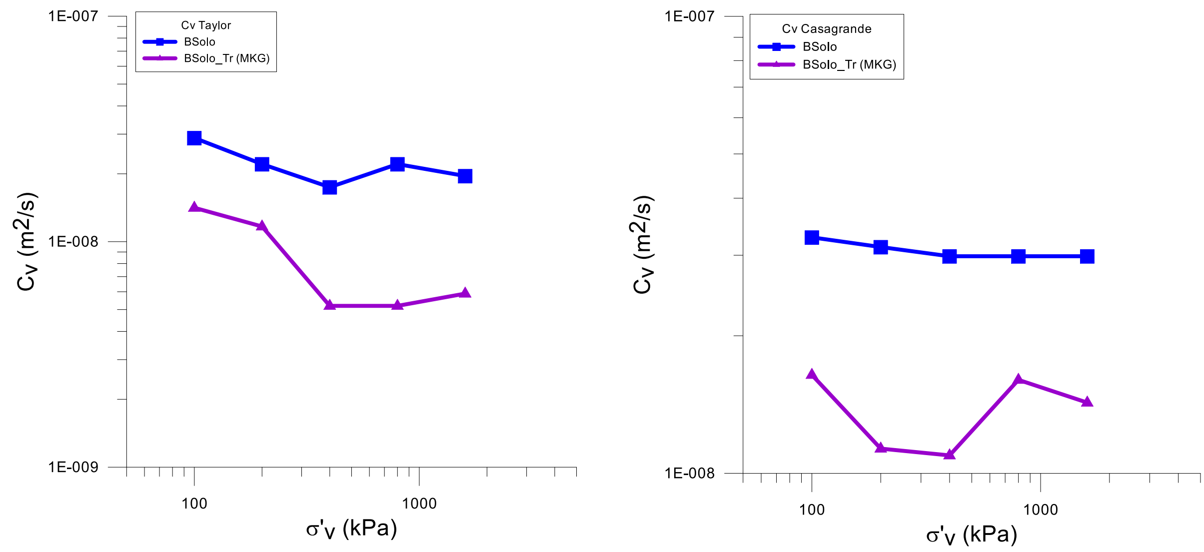

Figure 3. Variation of coefficient consolidation in function of σ'$_v$.

Figure 3. show changes in the coefficient of consolidation (Taylor method) according to the effective vertical stress. For Natural Soil, starting from 400 kPa point, the C_v coefficient decreases slightly. On contrary, the observed change is related to the characteristic of highly plastic clays. The values of C_v for these materials result in permeability variations during the test, they are calculated by eq. 4:

$$K_v = \frac{C_v \gamma_w}{E_{oed}} \quad (4)$$

Where E_{oed} is the oedometric module $E_{oed} = \frac{d\sigma'_v}{d\varepsilon_v}$ and γ_w is the specific weight of water.

Figure 4a shows variations in the permeability of the materials according to effective vertical stress. The permeability of the natural remolded soil (Bengawan Solo soil) and MKG treated mixture fall more

rapidly from a stress of 400 kPa. This reduction in permeability from these stress levels might explained by the performance of C_c slopes during the oedometer test.
This can be interpreted by the variation of the microstructure: in the field of low-stress compression is due to compression of large inter-aggregate pores or inter-domain. This occurs with the expulsion of water molecules characterized by low physicochemical interaction clay-water.
During passage to the field of high stress, some other mechanism intervenes related to the interaction between the adsorbed water and the surface of the clay inside the domains. Eliminating this water becomes more difficult [5].

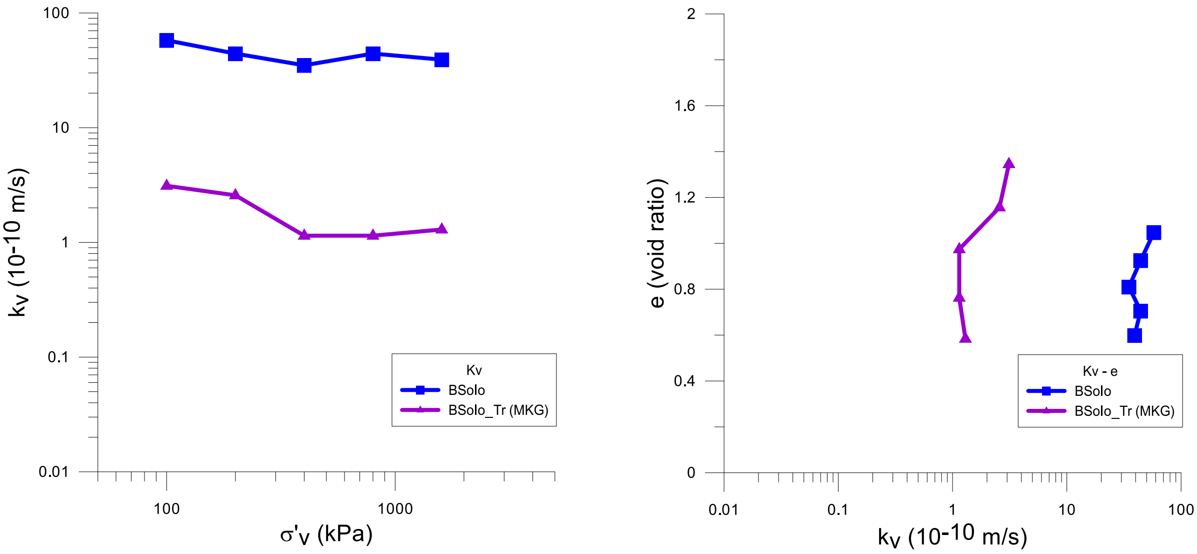

Figure 4. Variation of permeability in function of σ'_v.

The permeability of natural remoulded soil sample almost linearly decrease during the test but increases for Kaolin K13 treated. In Figure 4b., it could be seen that natural remoulded soil show changes in void ratio depending on the permeability: it is found that despite the high porosity (index high vacuum), its permeability is smaller than the permeability of other mixtures. This result is coherent with previous study [5].

4. Conclusions
From the assessment of material properties of natural and MKG treated soil. it can be conclude that:

- The compression curve shows that the implication of MKG for Bengawan Solo Silty Soil only have an influence in reducing swelling. This happen due to the chemical composition (Si/Al ratio) and treatment of the samples. In literature, mechanical behavior of samples could be augment if the soil cured in certain temperature and time.
- Natural remoulded soil compression curve is bending. It is followed by two tendencies; in the low stress domain, it expresses a process of progressive degradation of the cementation between the grains. In high stress domain $\sigma'v > 100$ kPa, the curve changes drastically and gives a high value of compression index. It corresponds to a cementation breaking between grains of material.
- The permeability of the natural remoulded soil and MKG treated soil mixture fall more rapidly from a stress of 400 kPa. This reduction in permeability from these stress levels might explained by the performance of C_c slopes during the oedometer test. It is found that despite the high porosity (index high vacuum), its permeability is smaller than the permeability of other mixtures.
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