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Experimental Study of Suction-Monitored CBR Test on Sand-Kaolin Clay Mixture

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ABSTRACT: Conventional laboratory CBR test has been widely used for predicting bearing capacity of subgrade layer for pavement design. In unsaturated soil, suction is one of the key parameters for understanding the soil behavior. The analysis of CBR is commonly presented in CBR-water content relation. The information of CBR based on soil suction is very rare and more study is still required. This paper presents a laboratory experiment of CBR test with direct suction measurement. Suction-monitored CBR test is introduced by attaching tensiometers on CBR mold and its surcharge. The standard compacted test on various proportions of sand-kaolin clay mixtures starting from 0% (pure sand), 5%, 10%, and 20% of clay were used. The tests were performed with different value of water content in both soaked and unsoaked conditions. The results indicated that the CBR versus matric suction forms a bi-linear curve. The discussion is presented in term of CBR-water content and CBR-matric suction relation.

Keywords: Bi-linear Curve, CBR, Matric Suction, Sand-Kaolin Mixture

1 INTRODUCTION

The California Bearing Ratio (CBR) has been used as a semi empirical approach for predicting bearing capacity of subgrade for pavement design. The method was firstly used in 1920's in the California State Highway Department and was adapted by US Corp of Engineer in the 1940's for military airfield. After the Second World War, the CBR was also used in UK and has spread to European countries [1]-[2]. Due to its simplicity and relatively low cost, this method has been widely used around the world for flexible pavement design.

The CBR test is performed by penetrating a plunger with constant penetration rate of 1.27 in/min on compacted specimen on rigid mould with diameter of 152.4 mm and a height of 177.8 mm as describe in ASTM D 1883-07. There are 2 types of CBR test associated with the treatment of the sample: unsoaked and soaked. The unsoaked CBR test is performed to simulate the natural condition whereas the soaked one is performed to replicate the worst condition such as high water table in the field, in which the soil layer is considered to be in saturated or nearly saturated condition.

The intensive study of the CBR and its relationship with water content and dry density has been studied by Davis [3] using a relatively wide range variation of soils from heavy clay to sandy gravel. The relation was presented in semi logarithm diagram, showing that the log CBR value was affected by water content, dry density and structure of soil particle. As water content increased, the CBR value went down linearly for plastic soil, whereas for non-plastic soils the relation was non-linear. The non-plastic the soil exhibited increasing in CBR at initial range of water content, and decreasing as the water content increased. This non linearity was believed as the effect of compaction on the soil structure of the soil.

Black [4] carried out the study to estimate the CBR value of cohesive soil indirectly using the soil plasticity and its moisture content. Firstly, soil suction and true angle of friction were predicted using soil suction-water content and true angle of friction-plasticity index curves respectively. From this, the predicted suction and the true angle of friction were used to calculate bearing capacity, and finally the CBR was estimated using the calculated bearing capacity.

Paraire [5] carried out the study for predicting CBR in unsaturated condition indirectly using bearing capacity approach. He performed the bearing capacity test using a small cone with an angle of 30^o and 2.03 cm in diameter penetrated on the surface of silt and quartz sand specimen with similar dimension of CBR mould. During the test, suction was generated using suction plate apparatus and water content was also measured. The CBR was indirectly obtained from the large number of suction-bearing capacity data. The result indicated that there was a non-linear suction-CBR relation in which the increase in suction caused the increase in CBR.

The non-linearity of CBR with respect to matric suction was also resulted from the study carried out by Sivakumar and Tan [6]. They investigated the effect of compacted water content on CBR of tills, while matric suction was taken into consideration using a pressure plate. The effect of matric suction was presented indirectly by water content, and indicated that water content has a significant effect on CBR. The result also indicated that the rate increase in CBR at wet side of optimum water content was lower than that at dry side.

The effect of matric suction on CBR value has also been studied by Ampadu [7] on decomposed granite. He focused on the effect of drying and wetting of remolded specimen on CBR value. The result indicated that from the OMC the

CBR tends to increase rapidly as water content decreased. The CBR was drop as water content increased due to soaking. In his study, matric suction was obtained indirectly from SWCC using filter paper method.
The aforementioned studies indicated that many more investigations regarding the effect of matric suction on CBR were still required. This paper presents the experimental study of CBR on various proportions of sand-kaolin mixtures with direct measurement of matric suction using tensiometer.

2 SUCTION-MONITORED CBR DEVICE

The suction-monitored CBR is the device for CBR test in which matric suction is monitored during the test. It is made by a modification of conventional CBR by attaching 1-bar miniature tensiometers on its mold and surcharge weight. The set-up and configuration of the test is shown in Fig. 1. The tensiometers were connected to the data logger or readout unit so that the suction measurement together with the loading and displacement can be recorded continuously during the test.

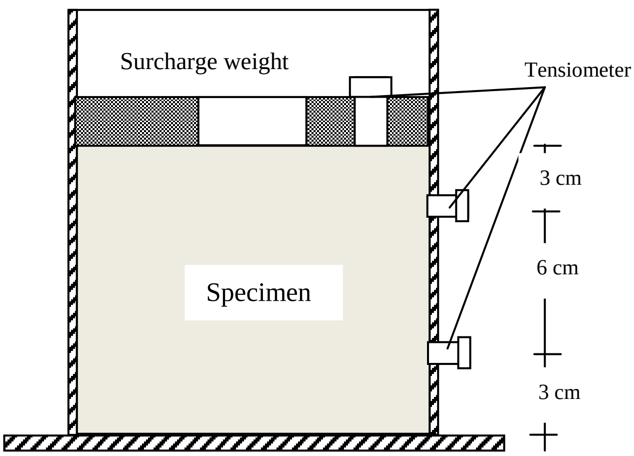

Fig. 1: The setup of modified CBR test (not to scale)

3 TESTING PROGRAM

3.1 Preparation

Sand-kaolin mixture with different proportion of 100% sand, 95:5, 90:10, 80:20 dry weight were investigated. The sand was taken from Baldivis sand pit, Western Australia, and has the specific gravity of 2.63. Grain size analysis indicated that it consists of 99.74 % fine and medium size of sand and 0.26 % of fines. According to the ASTM D 2487, this material is classified as poorly-graded sand (SP). The trade mark of kaolin clay was obtained from the UNIMIN Australia Ltd., and has the liquid limit and plasticity index of 48.1 and 17.4 respectively. The dry sand and kaolin clay were then mixed with the pure water according to the desired proportion and put in a sealed plastic bag for at least 72 hours for curing and water content equilibration. The compaction test was performed following the Proctor compaction procedure as described in ASTM D 698. The grain size distribution curves of all mixtures are shown in Fig. 2.

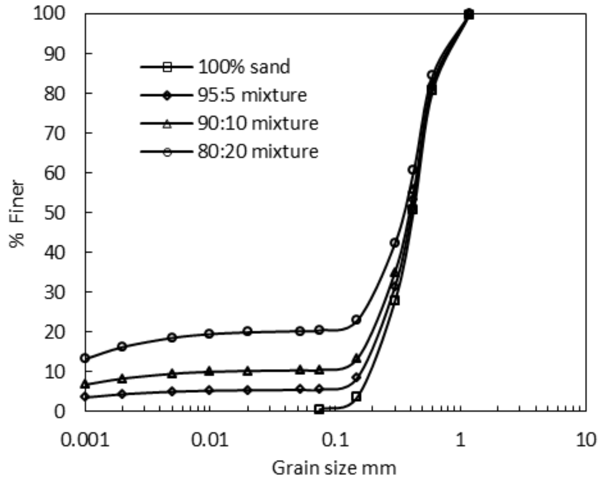

Fig. 2. Grain size distribution curves

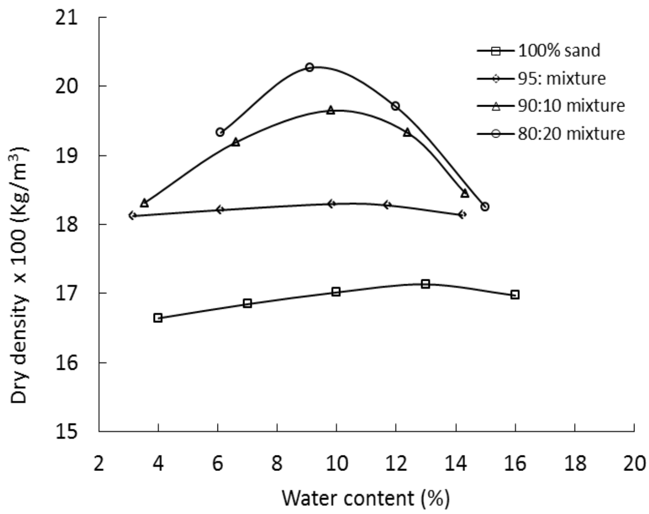

Fig. 3. Compaction curves

Fig. 3 and Table 1 show the compaction curves and compaction characteristic respectively. During compaction, the small particles of kaolin clay fill the voids causing the increase in MDD and the decrease in void ratio. This result has a good agreement with the result of Mullins and Panayiotopoulos [8] and Chiu and Shackelford [9]. The optimum water content (OWC) and maximum dry density (MDD) were two referenced parameters for the compaction of CBR specimens. The relatively high water content in 100% sand was caused by the high portion of fine size of sand (> 50%).

Table 1. Compaction characteristic of the sand-kaolin mixture

Sand-kaolin clay mixture	MDD (kg/m^3)	OWC (%)	Void ratio (e)
100% sand	1700	13	0.5
95:5	1830	11	0.41
90:10	1970	9.8	0.31
80:20	2030	9.1	0.27

Prior to the CBR compaction, the orifices prepared for attaching the tensiometers on the mold were blocked tightly with electrical tape. This was done to avoid the specimen coming out from the mold through these holes during compaction. The CBR tests were performed on both “saturated” and unsaturated conditions, represented by soaked and unsoaked specimen respectively.

It is essential to ensure that before and during matric suction measurement, the tensiometers were completely free of air bubbles. The presence even a small air bubble would have affected the performance of the tensiometer by increasing the response time. The saturation of tensiometers was then required. It was performed by immersing its ceramic disk and reservoir in the distilled water and then was vacuumed using a desiccator and a vacuum pump for around 2-3 hours.

3.2 Testing Program

Prior to plunger penetration, the tensiometers were installed through the orifices on the CBR mold and its surcharge in such a way that its high air entry disk (HAED) of tensiometers has a good contact with the specimen. High quality removable adhesive and clamping set were utilized to hold the tensiometers in their position. Pneumatic machine was utilized to penetrate the CBR plunger on the specimen with a constant rate of 1 mm/min. A load-penetration curve produced from the test was utilized for determining the CBR value. By definition, the CBR value is the magnitude of stress at which the specimen has been penetrated at 1 in (2.54 mm) compared to a standard stress of 6.9 MPa. During the test, the matric suction of the bottom and upper layers of the specimen were recorded. After the CBR test, the water content of the bottom, middle and top layer of specimen were determined. In this study, various water contents were obtained by air-drying for different time periods from unsoaked specimens.

4 RESULTS

4.1 The Effect of Clay Content and Air Drying Period on CBR

Fig. 4 shows the effect of kaolin clay content on CBR for various periods of time. The CBR of 100% sand (0% kaolin clay content) are not significantly affected by the water content, as the CBR values remain around 15-20% at any water content. The increase of kaolin clay content up to 5% causes the decrease in CBR in both soaked and unsoaked condition, but it causes a slight increase in CBR when the specimens were dried up for 1 or 2.5 day. The significant increase in CBR is shown by 10% kaolin clay content (90:10 mixture) when the specimen was dried up. The mixture of 90:10 exhibits the best proportion in term of CBR (even though according to compaction curves, the highest MDD was resulted from 80:20 mixture). The CBR of 90:10 mixture increases from 18.6% in soaked condition to 28.3% in unsoaked condition. Again, the CBR increases to 41.3% and 48.5%, when the sample was dried up for 1 and 2.5 days respectively. Beyond 10% kaolin clay content, the CBR decreases even though the samples were air-dried.
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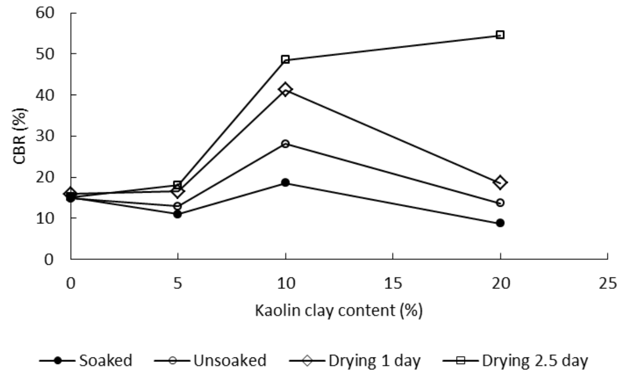

Fig. 4. The effect of kaolin clay content on CBR

4.2 The Effect of Water Content and Matric Suction on CBR

Fig. 5 quantifies the effect of the decrease in water content due to air-drying on CBR. The CBR-water content relation forms a non-linear curve. Until its water content reaches the OWC, the CBR increases slightly as the water content decreases, and a significant increase rate in CBR occurs when the water content is less than OWC. The result has a good agreement with the result of Ampadu [7]. In general, the longer the air-drying period, the lower the specimen water content and the higher the CBR value.

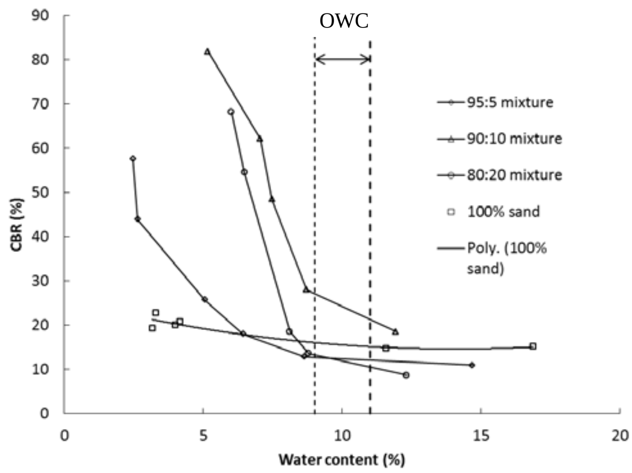

Fig. 5. The effect of water content on CBR

The effect of water content and matric suction on the strength of compacted sand-kaolin mixtures has been investigated as part of the author’s study. The result indicated that to some extent the presence of kaolin clay affected the shear strength through the increase of effective cohesion and the decrease of effective internal friction angle. However, the cohesion itself was affected by the amount of water in the mixture. Accordingly, it may be deduced that the CBR of compacted sand-kaolin clay mixture is affected by the combination effect of kaolin clay and water content altogether.

It has been recognized that the decrease in water content leads to the increase in matric suction. The effect of the increased matric suction on the CBR is presented in Fig. 6. This result may be explained as the decrease in water content due to drying causes the increase in water tension amongst the soil particles causing the increase in matric suction, and as a consequence, causing the increase in strength.

It can be observed from the figure that the relation between CBR and matric suction forms a bi-linear curve. The first part of the curve starts from near zero matric suction (soaked sample) to 5-7 kPa, at which the CBR increases sharply, and the second part starts from 5-7 kPa with a relatively slower increase in CBR. It also can be seen that the matric suction has never attained zero even though the sample was soaked for 4 days. The soaked CBR test was not performed in the fully saturated condition. The reason is that the test was performed 15 minutes after removing the mold from the bath. Some of the water in the specimen may infiltrate through the base, and some of them may evaporate.

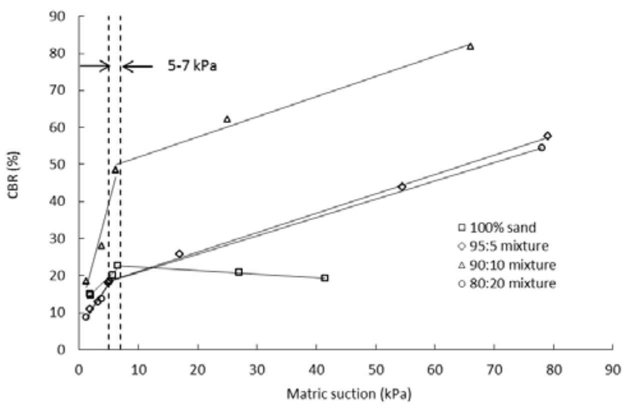

Fig. 6. Bi-linear curve of CBR versus matric suction relation

5 SUMMARY AND CONCLUSION

Based on the laboratory testing on CBR with suction measurement, it can be concluded:

1. Suction-monitored CBR is modification of conventional CBR by attaching tensiometers on its mould and surcharge weight.
2. The CBR test was performed on sand-kaolin clay mixtures of 100% sand, 95:5, 90:10, and 80:20 dry weight proportion, combined with the variation of water content and matric suction using air-dying method.
3. The CBR value of each mixture was presented in respect to water content and matric suction. The decrease in water content leads to the increase in matric suction, and the increase in matric suction leads to the increase in CBR.
4. The relation between CBR versus water content and also the CBR versus matric suction are non-linear. Until the water content reaches the OWC, the CBR increases slightly as the water content decreases. A significant increase rate in CBR value occurs when the specimen water content is less than its OWC.
5. In this study, the non-linearity of CBR in respect to matric suction forms a bi-linear curve for all mixtures. The first part of the curve at which the CBR increases sharply is started at near zero matric suction (soaked sample) until 5-7 kPa, continued by a relatively slower increase in CBR at the second part of the curve. For 100% sand, the second part of the curve exhibits the decrease in CBR even though the matric suction is increased.
6. Further study is required using the device with higher matric suction capacity such as suction probe, and also using the wider range of soil types.

6. ACKNOWLEDGEMENTS

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