Unconfined Compression Strength of Compacted Swelling Clay Soils from Sudan

Résistance à la compression non confinée des argiles gonflantes compactées du Soudan

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ABSTRACT: Despite their problematic nature, swelling clays have been extensively used for the construction of road and dam embankments in central and eastern Sudan. The embankments of Roseiris dam are typical examples. Extensive quality control data was collected from the earthwork construction activities during the first stage heightening of the dam. The data included soil classification and index parameters, Proctor compaction parameters and unconfined compression strength values. Statistical analysis of the data showed good relationship between the unconfined compression strength of compacted specimens and combination of soil intrinsic and placement properties. The correlation relationship depends mainly on the molding water content. Limiting water content exists below which the relationship is poor and beyond which the relationship is good.

RÉSUMÉ : Malgré leur caractère problématique, les argiles gonflantes ont été largement utilisées pour la construction des routes de même que les digues de barrages dans le centre et l'est du Soudan. Les digues du barrage de Roseiris constituent des exemples typiques. Des données exhaustives sur le contrôle de la qualité ont été recueillies lors des travaux de construction de terrassements au cours de la première phase de rehaussement du barrage. Les données comprenaient la classification des sols, les paramètres de l'indice, les paramètres de compactage de Proctor et les valeurs de résistance à la compression non confinées. L'analyse statistique des données a montré une bonne relation entre la résistance à la compression non compacte des spécimens compactés, la combinaison des propriétés intrinsèques et de placement du sol. La relation de corrélation dépend principalement de la teneur en eau de moulage. La limitation de la teneur en eau existant en dessous de laquelle la relation est pauvre et au-delà de laquelle la relation est bonne.

KEYWORDS: unconfined strength, compacted swelling clay.

1 INTRODUCTION

Highly plastic tropical clays "black cotton soils" cover large plains in the central and eastern Sudan. Most of the development projects e.g. roads, irrigation canals and factories are located in these clay plains. They are characterized by their high plasticity, high potential for swelling and shrinkage. Despite their problematic nature, large quantities of black cotton clays are used as embankment materials. Road embankments and the clay cores and embankments of several dams were constructed from swelling soils obtained from borrow areas adjacent to their construction sites.

The placement of embankment materials usually requires moisture conditioning, compaction in layers and quality control. The quality control dictates performing routine laboratory and field tests such as water content, classification tests, Proctor compaction, insitu density and unconfined compression test. The latter is needed for easy determination of the undrained shear strength of the compacted soils.

This paper analyzes intensive field data obtained/collected from the studies and quality control activities of Roseiris Dam heightening project during the eighties of the twentieth century. Classification tests, Proctor compaction tests and unconfined compression tests were performed on clay samples intended for use as core material for the earth dam. The data is analyzed to study the different soil intrinsic and placement parameters affecting the unconfined compression strength.

2 GEOLOGICAL BACKGROUND

The Central Plains of Sudan are covered with dark grey to brown alluvial silty clay or clayey silt soils often mixed with calcareous concretions. The sediments had been deposited by the Blue and White Nile rivers. They are weathered sediments which had been mainly derived from the Ethiopian Highlands and the equatorial regions of Africa. The clay is montmorillionitic with small amounts of kaolinite and illite minerals (Elsharief and Moustafa 2012).

3 THE FACTORS AFFECTING THE STRENGTH OF COMPACTED SOILS

The strength and volume change characteristics of unsaturated clayey soils are known to be influenced and controlled by: the soil intrinsic properties such as its grain size constituents, the clay mineralogy, liquid limit (LL) plasticity index (PI); soil placement factors such as moisture content (m.c), degree of saturation (Sr), density and applied stresses; and environmental factors such as the amount of absorbed or lost water (Mohamed 1986; Shreinder, 1987). Efforts had been made to study and predict the strength and swelling parameters of active clays by introducing factors that combine the soil intrinsic and placement properties of expansive clays from Sudan (Mohamed 1986; Zumrawi 2000, Elsharief et al 2014). Elsharief (2011) showed that the unconfined compression strength of compacted black cotton clays is influenced by the factor m.c/PI. The data used was mostly for soils classified as highly plastic silt (MH). Very good relationship was found for (m.c/PI) greater than 1.0 whereas a lot scatter was experienced for m.c/PI smaller than 1.0. Salam (2014) introduced another factor (Fc) which combines intrinsic and placement properties for the prediction of swelling pressure of swelling soils from Sudan. The parameter is given by the following equation:

$$Fc = CI * \square d \qquad (1)$$

Where CI is the consistency index (LL-m.c)/PI; and □d is the dry density.

Nagarj et al (1991) introduced the parameter e*Sr$^{1/3}$ for the prediction of the shear strength and volume change behavior of unsaturated soils from India.

4 THE COLLECTED DATA

The data was collected during the search for potential sources for construction material and construction activities of Roseiris dam heightening project in South-Eastern Sudan. The dam constitutes concrete gravity dam in the course of the river and zoned embankment dams on both sides of the concrete dam. It was planned to add and place over one million cubic meters of core material in the zoned embankment dams. Several sources were investigated in the vicinity of the dam site. Bulk soil samples were collected during construction and from over 70 test pits excavated in several borrow areas close to the proposed embankments.

Basic classification tests (grain size distribution and Atterberg limits) were performed on all the bulk samples. The liquid limit and plasticity index data were plotted on Cassagrande Chart (Figure 1). Normal Proctor compaction test was also performed on the bulk samples. Over 300 unconfined compression strength (UCS) tests were performed on the compacted specimens, i.e. average of five UCS tests for each sample. The data was analyzed to define the soil parameters which affect the unconfined compression strength of the partly saturated compacted soils.

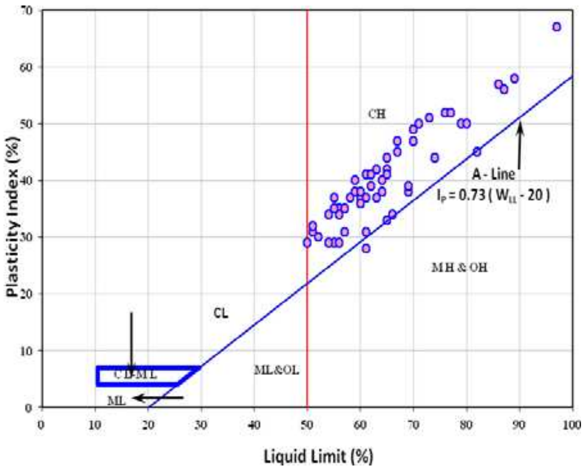

Figure 1. Cassagrande Chart

5 RESULTS AND DISCUSSION

The studied samples are classified as CH, according to the Unified Soil Classification System (Figure 1). The soils are highly plastic and known to be potentially expansive. The compaction water contents of the tested specimens range from dry of optimum to wet of optimum. The LL ranges between 97-51 whereas the PI ranges between 67-31. The soils contain numerous calcareous concretions which were removed from the soil during the classification tests.

The UCS was plotted against moisture content for three selected soils (LL equals 89, 74 and 59; PI is 58, 44 and 38) representing very high plasticity, high plasticity and moderate plasticity (Figure 2). The optimum moisture is 28, 27 and 19 for the three samples, respectively. The UCS decreases with increase in moisture content of the compacted specimen, subjected to the same compaction energy, showing variation trends similar to that of the soil water characteristic curve (SWCC) of similar CH clay soils. A typical SWCC for a clay soil from Alfao is shown in Figure 3 (Abdelaziz, 2014). The shape of the SWCC constitutes two relationships or portions represented by two straight lines that intersect at the air entry value. Matric suction is very sensitive to changes in moisture content when moisture content is less than the air entry value. This indicates some kind of inter-relationship between UCS and matric suction. The decrease of UCS with increase in moisture content is more when the specimen is on the dry of optimum side.

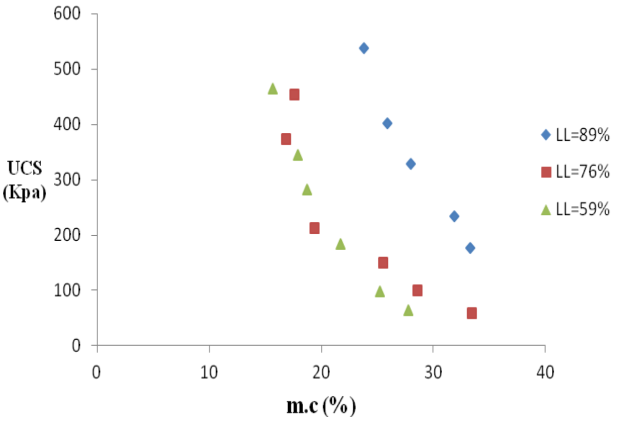

Figure 2. UCS versus m.c for three selected specimens

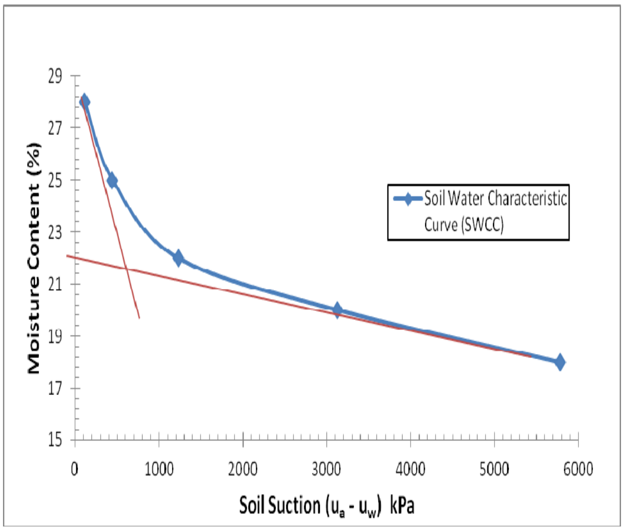

Figure 3. UCS Soil Water Characteristic Curve for soil from Alfao (Abdelaziz 2014)

The UCS was plotted against the factor m.c/PI for all the collected data (Figure 4). There is clear trend of decrease of UCS with increase in m.c/PI. The scatter is attributed to different factors among which are the large variation in the plastic properties of the soils, the influence of the dry density as important placement parameter and the effects of the calcareous concretions present in the samples. An attempt was made to plot UCS versus m.c/LL but large scatter was observed. This clearly supports the claim that plasticity index predicts the engineering properties of clays better than the LL (Nagaraj and Jayadeva, 1983).

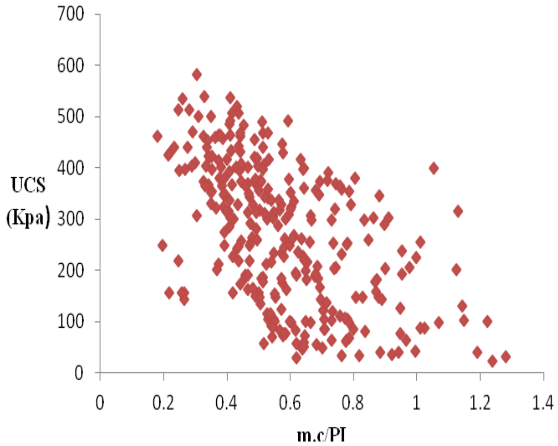

Figure 4. UCS versus m.c/PI for all specimens

The UCS is also plotted against the Fc factor identified above (Figure 5). The UCS increases with Fc showing considerable scatter as Fc increases beyond 1.2. Better trends are expected on grouping the data according to their plasticity which indirectly reflects their activity and hence their response to moisture variations.

Multiple linear regression analysis was performed on the data. Good relationship was found between UCS and the cubic root of the degree of saturation, void ratio and Atterberg Limits. The analysis revealed the following relationship

$$Logqu = 6.252-1.808*Sr^{1/3} - 0.986*e+3.201*LL-3.001*PI-0.656*LI \quad (2)$$

Where (LI) is liquidity index, (Sr) is degree of saturation and (e) is the void ratio. A coefficient of correlation (R-squared) of 0.74 was obtained which indicates reasonable relationship.

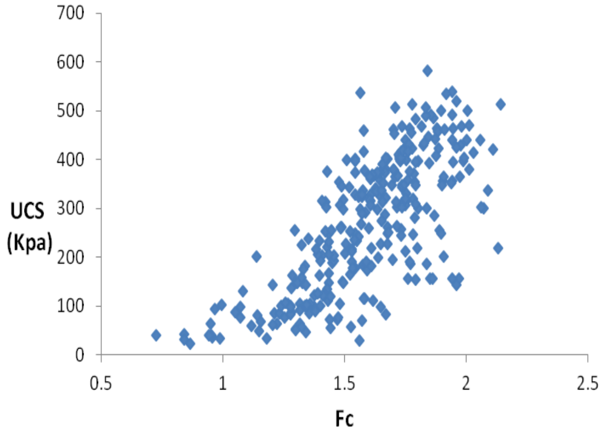

Figure 5. UCS versus Fc factor

6 CONCLUSION

The unconfined compression strength is an important soil parameter for the evaluation of the stability of compacted clay embankments. Over seventy bulk soil samples were collected during Roseiris dam heightening project. Classification tests and Proctor compaction were performed on all the bulk samples whereas the unconfined compression test was performed on all the specimens of the Proctor test. The data was analyzed to study the soil parameters which influence and affect the unconfined strength.

The analyzed data covered wide ranges of plasticity and grain size constituents. The UCS is controlled by several intrinsic and placement parameters and can't be related to a single soil parameter. The factors m.c/PI and Fc which combine intrinsic and placement parameters gave acceptable relationship and trends for the whole data; however better trends could be explored by grouping the data, based on their plasticity and water contents or matric suction. Reasonable correlation was found between the unconfined compression strength and the cubic root of the degree of saturation, void ratio, Atterberg limits and liquidity index.

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