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Evaluation of Effect of Cementation on Drained Shear Strength of Overconsolidated Clay Soils

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Abstract: The shear strength of soils is due to resistance against movement of soil grains at their contact area which is caused by interlocking and existing bonds between the grains chemical bond is one kind of bonds existed between soil grains that is due to the existance of calcium carbonate and it is called cementation and it could be important factor in increase in shear strength of overconsolidated clay soils. in order to evaluate the effect of cementation on shear strength of soils a mixture of 70% sand and 30% bentonite clay were used. To this mixture a 5% cement by dry weight was added and overconsolidated compacted samples cured for 7 and 28 days were prepared and tested in direct shear machine. The results were compared with the results of tests on uncemented samples. The results showed higher shear strength for cemented samples as expected. With the increase in cementation the coefficient **m** of overconsoldated shear strength decreased and the shear strength increased.

Key words: Cohesion · Cementation · Shear strength · Inter grain bond

INTRODUCTION

One of important subject in geotechnical engineering that has been evaluated extensively over long period of time is shear strength of soils. Of many factors affecting shear strength of soils directly or indirectly, density, effective stress and soil structure are the most important. The intact shear strength of over consolidated soil can be obtained from $\tau_{oc}=\tau_{NC}(OCR)^{1-m}$. In that the intact shear strength of over consolidated soils are higher than shear strength of normally consolidated soils of the same constituent by factor of $(OCR)^{1-m}$ [1]. The intact strength envelope of over consolidated clays and clay shales displays a pronounced curvature because swelling and softening intensify as effective normal stress decreases toward zero [2]. Shear strength of soils is due to the resistance against movement at the soil grains contacts. This resistance with the increase in normal stress between the grains and bond formation at contact area together with interlocking of grains cause resistance to shear or tangential movements. The existing bonds are physical and chemical types. The main mechanism responsible for physical bond is primary valence as a response to the increase in vertical effective stress in soil mass [3]. In this type of bond surface atoms at contact area of grains share electrons, therefore,it has a physical nature. Another type of bond between soil grains that causes the inrease in strength is chemical bonds of cementation. In this type of bond, soil grains are linked by a solid material such as calcium carbonate and in order to break these bonds more shear forces are required that cause the increase in shear strength. Mesri and Abdolghafar, introduced cohesion intercept **c'** as an important factor in slope stability of clayey soils. In Figur 1, the location of critical slide surface at three different values of cohesion related to London clay soil is shown. In this figure, the increase in factor of safety depends very much to the assumed cohesion at the sliding surface. The failure envelope for overconsolidated soils is curved, therefore, each value of cohesion **c'** is obtained at a particuler range of this curved envelope [4, 6].

As will be mentioned definition of shear strength of overconsolidated cemented clay is more appropriate to be defined in terms of shear strength of normally consolidated clay with the same composition multiply by a factor $(OCR)^{1-m}$. The effect of variable cementation on the parameter **m** is sought in this research.

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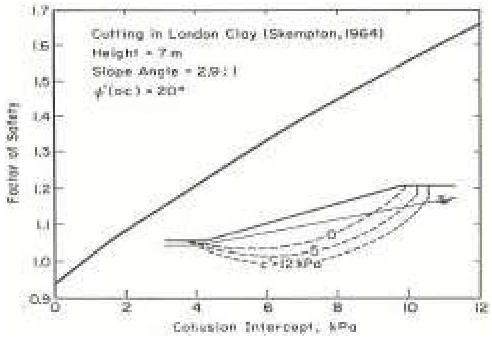

Fig. 1: Three sliding surface in London clay [4]

Fig. 2: Preservation of cemented samples during curing

Table 1: Index properties of bentonit-sand mixture

(%) LL	(%)PL	(%) PI	(%) ω_{opt}	(%) CF	A_C
88	21.1	66.9	18	32.5	2.06

METHODS AND MATERIALS

In order to evaluate the effect of cementation bond on shear strength and related factors, in soil composition containing 70% sand and 30% bentonite, two different cementation process was created. The sand was clean sand passing through NO. 40 seive and bentonite clay had liquid limit of 293 and plasticity index of 184. In Table 1, mixture properties are shown [3].

In order to create cementation in soil, 5% by dry weight Portland cement was mixed with the soil at the optimum water content. The samples thus prepared were compacted according to the proctor standard. Samples were then fitted into consolidation ring and placed in oedometer and loaded incrementally to final pressure of 1532 kpa in the presence of water. Each sample was then unloaded first to a pressure that was supposed to be applied during shearing in direct shear test. In this unloading stage, unloading was performed in the presence of water and sample was allowed to swell. In the second stage, the water in the oedometer cell was emptied first and unloading was performed in a single stage and in very short time and the sample was then taken out of the ring and wraped in plastic bags and waxed, Figur 2. For each series two specimens were prepared according to the above procedure, one was cured for 7 days and second one was cured for 28 days. The samples were then tested in direct shear after curing. Figure 3 shows the effective normal stresses at which overconsolidated samples were sheared.

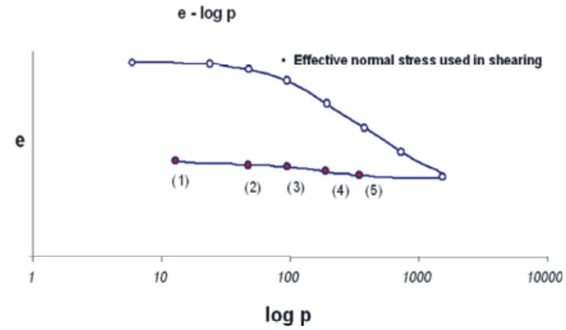

Fig. 3: Location of effective normal stress of overconsolidated samples during direct shear tests.

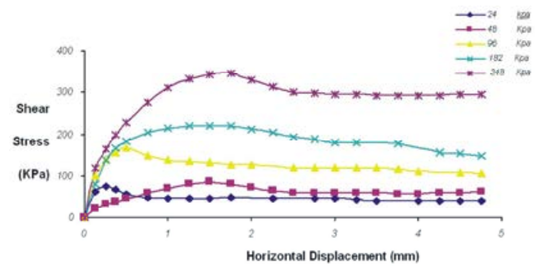

Fig. 4: Shear stress-horizontal displacement for samples with cement and 7days curing period

RESULT AND DISCUSSION

Shear stress versus horizontal displacement for cemented and uncemented samples are shown in Figures 4-6. As expected the cemented samples at every effective normal stress showed higher shear stress. Samples with 28 days of curing showed about 40% higher strength than samples with 7 days of curing. Furthermore, cemented samples showed more brittle failure than uncemented samples. These samples with cementation bonds resisted more against displacement and with the increase in shear stress, bonds were broken and the shear stress versus, horizontal displacement relationship for cemented samples had a distinct peak as compared with uncemented samples.

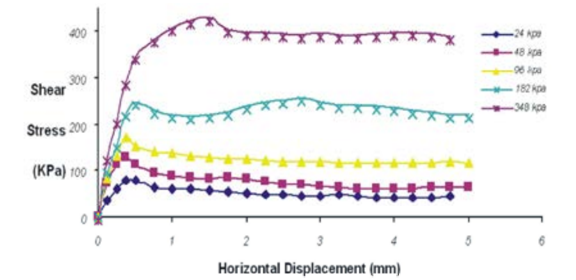

Fig. 5: Shear stress-horizontal displacement for samples with cement and 28 days curing period

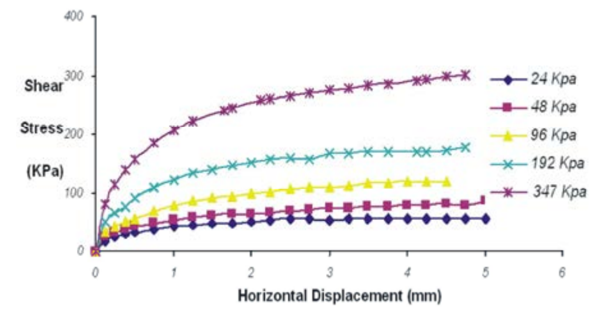

Fig. 6: Shear stress-horizontal displacement for samples without cement

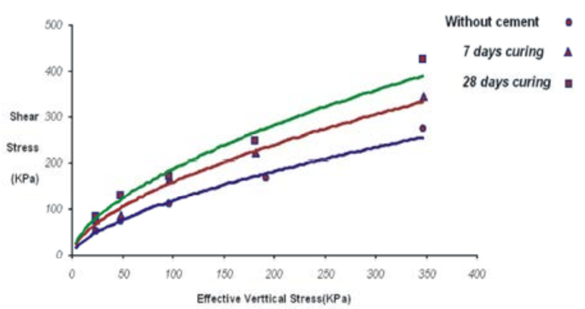

Fig. 7: Comparison of failure envelopes of cemented and uncemented samples

Failure Envelope: In Figure 7, failure envelopes of compacted overconsolidated bentonite 30% and sand 70% mixture in three cementation condition are shown. In these envelopes, the increase in effective normal stress caused the increase in physical and chemical bonds and with continuation of this increase, due to decrease in rate of increase in grains contact area and broken chemical bonds, the rate of increase in shear stress is decreased and thus a curved envelope is obtained. In Figure 7 the difference in shear strength at each density and effective vertical stress is due to the presence of cementation between the grains. At each effective normal stress due to stronger cementation bonds more shear strength is obtained. Therefore, we can say that the existense of chemical bonds is one of important causes in forming strength in cemented soils. With the increase in cementation more curvature in failure envelope is developed. The changes in normal effective stress directly affect the physical bonds and indirectly the chemical bonds between the grains. The curvature is due to both physical and chemical bonds. However in cemented soils differentiation between the effect of both chemical and physical bond is impossible. But the comparison of the three failure envelope obtained from one fixed composition with different cementation in Figure 7 shows that at the same effective normal stress the increase in shear strength is due to cementation. For example at the effective normal stress of 348 KPa drained shear strength of the specimens without cement, with cement and 7 day curing and with cement and 28 days curing is 275,346 and 425kpa respectively. The difference of 71 and 79 KPa in shear strength is only due to cementation.

Determination of Parameter M and c': The failure envelope of overconsolidated soils have distinct curvature and from low to high normal stresses, a great change in slope and intercept exists and this curvature depends very much on overconsolidated pressure and over consolidation ratio. Collection of these shear strength for overconsolidated clay soils in terms of **c'** and Ø(oc) due to their variation is meaningless. Therefore shear strength of overconsolidated clay soil can be expressed in terms of normaly consolidated drained shear strength of the same composition as defined by Eq. (1) [5].

$$S = \sigma' \tan \phi' . (OCR)^{1-m} \tag{1}$$

Therefore according to Eq.(1) the intact shear strength of an overconsolidated clay soil by a factor of $(OCR)^{1-m}$ is higher than shear strength of the same composition in normaly consolidated state. The value of **m** for each composition is a constant and independent of $\boldsymbol{\sigma'_n}$ and for overconsolidated clay compositions with the same overconsolidated pressure, the value of **m** could be representative of the curvature in the failure envelope. High curvature of failure envelope means lower m and for very low curvature the magnitude of m nears one. Recently, low curvature failure envelopes has been also reported for fully softened and residual states [2]. If log of shear stress is drawn against log of normal stress the slope of the line thus obtained is the value of parameter **m**. The intercept of the line with shear stress axis is

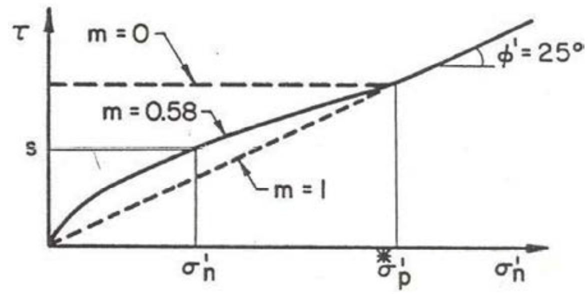

Fig. 8: Effect of curvature of failure envelope on the parameter m [4]

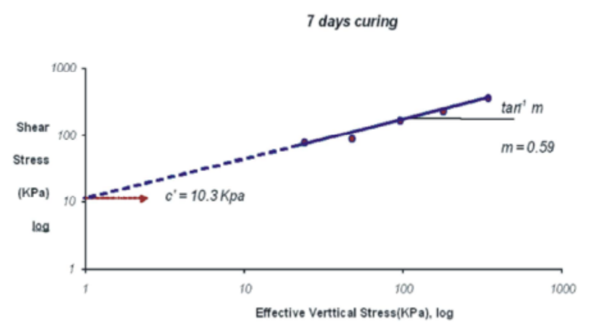

Fig. 9: Parameter m and cohesion intercept **c'** for samples with cement with 7 days curing time

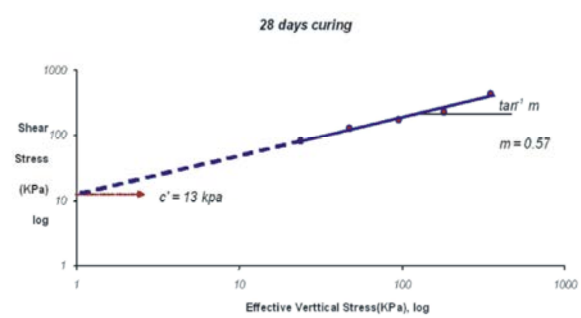

Fig. 10: Parameter m and cohesion intercept **c'** for samples with cement with 28 days curing time

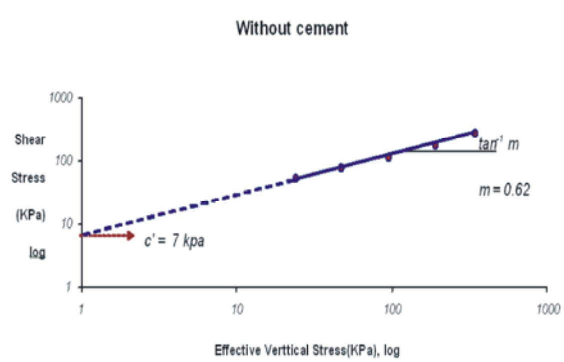

Fig. 11: Parameter m and cohesion intercept **c'** for samples with cement without cement

Table 2: value of m for different degree of cementation

Degree of cementation	Without cement	7 days curing	28 days curing
M	0.62	0.59	0.57
C'(Kpa)	9	10.3	13

cohesion **c'**. The range for parameter **m** begins from 1 for soft and normaly consolidated clay and varies to close zero for intact cemented clays, Figure 8. In Figures 9,10 and 11 values of parameter m and cohesion **c'** for mixtures of bentonite-sand with and without cement are obtained. In Table 2 these values are tabulated. According to data shown in Table 2, with the increase in cementation, the cohesion **c'** is increased and the value of m decreased.

CONCLUSION

Compositions that contain high cementation bond between grains have higher drained shear strength tham similar compositions without cementation bond. These compositions due to shear resistance of grains against displacement experience brittle behavior during shearing. Higher degree of cementation leads to higher shear strength, higher cohesion **c'** and lower **m** value. Inter grains bonds and overconsolidation ratio (OCR) are important variables affecting drained shear strength of overconsolidated clay soils.

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