Short Communication

Strength Behaviour of Pilani Soil

by

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Introduction

The importance of the study of shear strength in the Civil Engineering field need hardly be stressed. Several investigations have been conducted in the past to better the understanding of the behaviour of clays as affected by various factors such as type of clay mineral, nature of pore water, soil structure, temperature etc. It is well known that clay particles carry overall negative charges and the surface area to mass ratio of most clay particles is sufficiently high. Because of this the forces at particle surfaces strongly influence the behaviour of particles and their aggregations. The importance of the interparticle electrical attractive and repulsive forces in influencing the engineering behaviour of clays has been well established in the literature (Rosenqvist 1955; Lambe 1960a). Recently, the senior author (Venkatappa Rao 1972) brought out the physico-chemical mechanisms governing the strength and volume change behaviour of Kaolinite and montmorillonite clays. An attempt is made in the present investigation to verify the strength behaviour in regard to a natural soil with high percentage of silt and sand.

Modified Effective Stress Concept

Terzaghi's (1923) concept of effective stress has been used very widely for explaining the strength and deformation characteristics of saturated soils. The effective stress (σ') was defined as the excess of the total applied stress (σ) over the pore water pressure (u).

Lambe (1960a) introduced an equation relating the total external force to the internal forces in the particulate system which include the electrical attractive and repulsive forces. He further, (Lambe 1960b) attempted to define the effective stress as,

$$\sigma' = \sigma - u_a . a_a - u_w . a_w$$

$$= \bar{\bar{\sigma}} a_m + R - A \qquad \ldots(1)$$

where,

$\bar{\bar{\sigma}}$ = mineral to mineral contact stress,

a_m = fraction of the total interparticle area that is mineral to mineral contact.

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u_a = mineral-air contact stress.

a_a = fraction of total interparticle area that is mineral-air contact.

u_w = pore water pressure.

a_w = fraction of total interparticle area that is mineral-water water contact.

R = total interparticle electrical repulsion divided by total interparticle area.

A = total interparticle electrical attraction divided by total interparticle area.

By this equation, it is seen that the effective stress increases with the repulsive force (R) and decreases with the attractive force (A) which does not agree with the physical behaviour. This has been realised by Sridharan (1968) who modified Lambe's equation as,

$$\bar{C} = \bar{\bar{\sigma}}\, a_m = \sigma - \bar{u}_w - \bar{u}_a - R + A \qquad \ldots(2)$$

where,

$\bar{C}$ = effective contact stress

$\bar{u}_w$ = effective pore water pressure

$\bar{u}_a$ = effective pore air pressure.

The parameter $\bar{C}$ represents the effective contact stress between the particles and it was hypothesized that the effective stress $\bar{C}$ is the stress controlling the shearing resistance which corresponds to the conventional effective stress. According to this equation, the effective stress $\bar{C}$ increases with an increase in A and decrease in R. There is a fundamental difference between the definitions given by Lambe and Sridharan for the effective stress concept. While the difference between the external normal stress and effective pore water pressure is defined as effective stress by Lambe, Sridharan hypothesized $\bar{C}$ (the effective contact stress) as given by Equation. (2) as the effective stress controlling shearing strength.

Recently, the Senior Author (Venkatappa Rao, 1972) has used variations in electrical forces to understand the physico-chemical mechanisms governing the diverse engineering properties of clays in the light of the modified effective stress concept. That study was mainly concerned with the behaviour of kaolinite and montmorillonite clays with the variation in electrical forces brought about by changing the nature of the pore fluid using different organic solvents. In nature, the variation in attractive and repulsive forces for soils can be brought about by stress history which changes the particle orientation and effective distance between particles. Changes in salt concentration, changes in electrolyte fluid, chemical changes comprising weathering and other similar actions may bring about significant changes in the electrical attractive and repulsive forces (Kenney et al 1967). Hence the aim of the present study is to investigate the effect of change in electrical forces brought about by using different salt solutions on the strength of an aeolian soil (essentially a silty clay). Thus, it has been attempted to verify the strength mechanisms proposed earlier (Venkatappa Rao, 1972) for a more natural system. Further, an attempt has also been made to keep the soil fabric same, while obtaining samples of different pore fluids.

Experimental Work

Soil Studied

In this investigation the clay soil available in the vicinity of Pilani is mode use of. This area being located in the semi-arid to arid zone of the Rajastan desert, it is a wind blown deposit. This soil is the *terra-firma* over which the moving sand dunes lie. It is mostly azonal in nature. Most work reported here, has been conducted on soil passing through (ISI) Sieve No. 75. Some experiments have also been conducted on the unsieved soil. The Liquid Limit and the Plastic Limits of the soils used are 24 per cent and 14 per cent for the unsieved soil and 35 per cent and 19 per cent for the soil passing through ISI Sieve No. 75.

Pore Fluids Used

Molar solutions of calcium chloride and sodium chloride are used along with distilled water as pore fluids, to vary the interparticle forces of attraction and repulsion. The chlorides of calcium and sodium are chosen in preference to carbonate (particularly of calcium) so as to avoid pozzolonic effect.

Test Procedure

Consolidated drained tests were conducted on a box shear apparatus $60 \times 60 \times 20$ mm. The normal pressures used were 0.28, 0.56, 1.12 and 2.24 kg/cm^2. It is possible that samples remoulded with various pore fluids and consolidated may have different fabric, which make comparison and analysis difficult. In order to overcome this, oven dry soil was first compacted statically in the square mould to the required density and loaded to the desired pressure. Then the sample was quenched by pouring the required pore fluid and sufficient time (normally overnight) was allowed for volume changes (if any) and for complete saturation, before the start of the test. Complete saturation was ensured before the shearing was commenced which was done at a rate of 0.005 cm/Min.

For comparison purposes two series of tests were also conducted on hand remoulded samples of unsieved soil as also soil passing through I. S. Sieve No. 75 with distilled water as pore fluid. These samples, after hand remoulding were consolidated to the required pressure before commencement of the shear test. The other test details are same as for the earlier series.

Direct shear tests have been chosen in this study because of their simplicity and the relative ease for comparison purpose. Further, it affords the facility to obtain the samples with initially same fabric in the manner described above. Differences in measured strength have then been related to differences in the interparticle forces. The natural structure of the soil, in which other forces would contribute to shear strength – is not present in the samples, as all the samples are remoulded.

Test Results and Discussion

Figure 1 presents the results of the consolidated drained direct shear tests conducted on Pilani soil with different pore fluids. The angles of shearing resistance are also reported in the same Figure 1. It may be recalled that for Series I (statically compacted) an attempt has been made

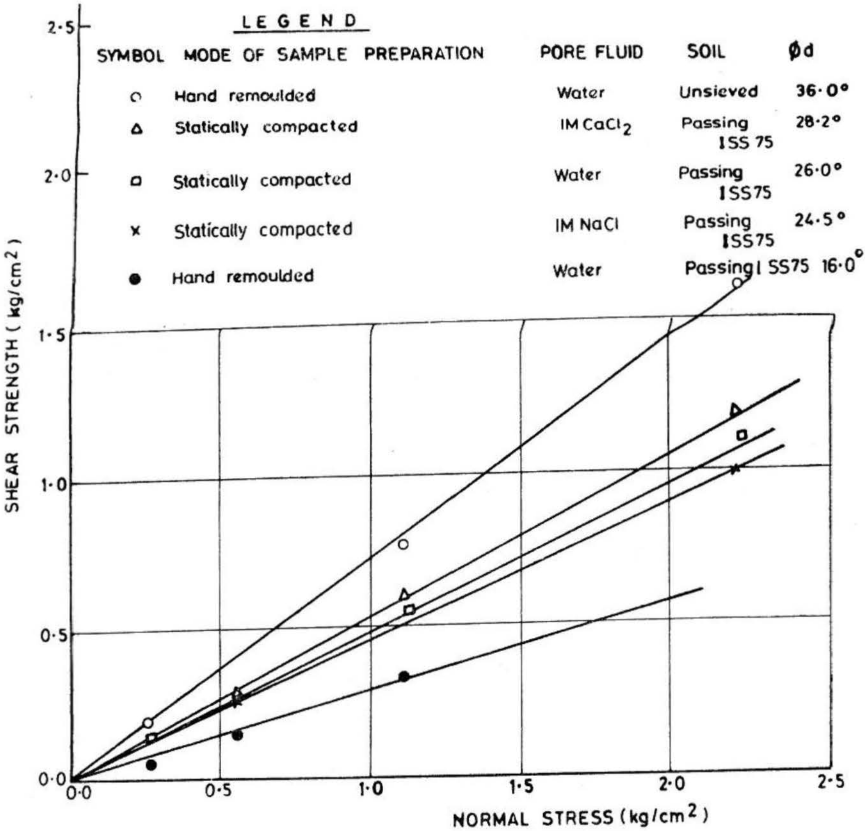

FIGURE 1. Strength lines for Pilani Soil with difforent pore fluids.

to keep the soil fabric same. Hence, differences in the shear strengths/angles of shearing resistance (ϕ_d) could only be attributed to changes in pore fluid. Comparing the results in Series I, it is seen that ϕ is the largest (28.2°) with $1M-CaCl_2$ as pore fluid and the least (24.5°) when $1M-NaCl$ is pore fluid, with that of distilled water (26.0°) falling in between.

It was stated earlier that, $\bar{C}$ the effective contact stress, is the stress controlling the shearing resistance at interparticle level. In earlier investigations (Venkatappa Rao, 1972; Sridharan and Venkatappa Rao, 1972, 1975), a change in the electrical forces R and A, (and hence, a change in $\bar{C}$) was brought out by the use of various organic pore fluids and it was conclusively proved that with increase in $\bar{C}$, the drained shearing strength also increases both for kaolinite and montmorillonite clays (i.e. non-swelling and swelling clays), irrespective of the mode of sample preparation. Thus, the strength behaviour is found to be in consistence with the modified effective stress concept.

In the present investigation, it was aimed to study the strength behaviour of a natural soil, in a more realistic environment (with two types of electrolytes) and view it from the stand point of the modified effective stress concept. Shear strength in the present study is considered to result from the differences between the interparticle forces, with interparticle attraction due mainly to van der Waals[1] forces and interparticle repulsion essentially owing to the diffuse double layer type. It is now well established that clay particles carry net negative charges. Due to this, diffuse ion layer are present around the particles, leading to interparticle repulsion due to osmotic activity of the ions. This force of repulsion decreases with increasing distance between the clay particles, with increasing electrolyte concentration and with increasing valence of the exchangeable ion (Verwey and Overbeek, 1948; Bolt, 1956). Hence, it could be postulated that for same type of clay soil and same ion concentration, the interparticle repulsive force is higher when sodium is the exchangeable cation than for calcium. According to Warkentin and Yong (1960), "*Increasing the Salt concentration and the valence of the exchangeable ions decreases the interparticle repulsion, and either increases or leaves unchanged the force of attraction.*" Thus it may be concluded that the net force of attraction is higher for calcium solution than for sodium solution with same electrolyte concentration. Hence, it follows from Equation (2) that $\overline{C}$, the effective contact stress is higher for calcium system, other things remaining same. Thus the shear strength is expected to be higher for a calcium system which is exactly the trend observed in Figure. 1.

Comparing the results of statically compacted and hand remoulded samples, with distilled water as pore fluid, it is observed that the strength in the case of the latter system is comparatively quite low. This may be due to the fact that the hand remoulded system tends to be more relatively oriented (dispersed) than the statically compacted one (Venkatappa Rao, 1972).

Further, comparing the result of the unsieved soils with that passing I.S. Sieve 75 with distilled water as pore fluid, both series being hand remoulded, it is seen that the former gives comparatively very high strength. This could be due to the larger amount of frictional resistance mobilised due to the larger sand and silt content present.

Summary and Conclusions

The investigations reported in this paper bring out the physical mechanisms involved in the strength behaviour of an aeolian soil. The modified effective stress concept, which considers the electrical attractive and repulsive forces, appears to explain satisfactorily the mechanism involved when different electrolytes are used as pore fluids.

The drained shearing strength is found to be highest for a calcium system and least for sodium system, (with that of distilled water falling in between), keeping the same initial soil fabric in all the three series.

Further, with distilled water as pore fluid, the strength of a hand remoulded system is found to be lower compared to that of a statically compacted system, wherein there could be less chances of orientation.

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