Correlation of Unconfined Compressive Strength of Soil with Size of the Test Specimen

by

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Introduction

SOIL engineers are trying hard to establish simple relations between fundamental properties of a soil mass and easily measurable parameters. Unconfined compressive strength is one of the parameters used in many foundation engineering problems. The strength depends on various factors including size, water content, plasticity etc. Jacky (1936) and Rutledge (1940) suggested that strength measured by unconfined compression test depends on the geometric proportions of the specimen. No relation correlating the strength with geometric proportions, however, has been developed so far. It is found easier to procure large chunk samples than tube samples during reconnaissance and investigation stage of any project. Chunk samples yield greatly improved quality of the undisturbed specimen and save enormous time in sampling. It is, therefore, considered worthwhile to investigate the relationship among unconfined compressive strength, size of the specimen and water content.

Unconfined Compression Condition

In the unconfined compressive test a soil specimen with a given water content fails under certain unique value of compressive load along a slippage plane, known as 'failure plane'. Normally consolidated dessicated soils and over consolidated soils, have numerous hair cracks, slickensides and fissures randomly scattered which join to develop the failure plane under failure stress conditions. In consequence, there is a possibility of reduction of measured strength with increased size of the specimen as a result of higher probability of the presence of cracks and other discontinuities.

In order to establish the relationship between measured laboratory strength and size of specimen, undisturbed samples of Black Cotton Soil at PUNE were tested in the laboratory.

Soil Samples

Black Cotton Soil, which is a problem soil in India has been chosen as the test sample for this investigation. This is a highly plastic, highly

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expansive and sensitive soil, and is grouped as 'CH' in unified classification. Many other investigators have established its properties which have been utilized in this study. Soil samples were taken out in the form of drive samples and chunk samples at different depths varying between 0.5 m to 2 m below ground level, from a pit very close to the river MULA. The soil sample had the following properties :—

(*a*) Liquid Limit ... 67%

(*b*) Plastic Limit ... 30%

(c) Average bulk density ... 1.75 gm/cc

(*d*) Average dry density ... 1.2 gm/cc

(*e*) Average specific gravity ... 2.70

(*f*) Average void ratio ... 1.16

(*g*) *p*H ... 8.45

The detailed procedure of unconfined compression testing as per ASTM (1968) was followed.

Relation between Water Content and Unconfined Compressive Strength

The experimental data was plotted as shown in Figure 1 and Figure 2. It was found that the strength varies with water content and fairly agrees with the results reported by Henkel (1960) and Ladd (1964).

The plot on arithmetical scale, between water content, w, and unconfined compressive strength, q_u, are shown in Figure 1. The same data was plotted on semilogarithmic graph paper, which gave approximately parallel straight lines for different sizes (Figure 2). The following relation is found to exist :—

$$w = M \text{ Log } q_u + N \quad \text{... (1)}$$

The values of parameters N and M were calculated for different sizes of specimen by the least squares method and are tabulated below :—

TABLE I

Value of slope M & Parameter N

Diameter, *D* Cm	Slope, *M*	Parametr, *N*
3.81	−0.197	0.4014
6.00	—0.193	0.3796
7.62	—0.190	0.3649
10.20	—0.193	0.3370
12.90	—0.192	0.3200
17.00	—0.192	0.3002
20.35	—0.191	0.2882

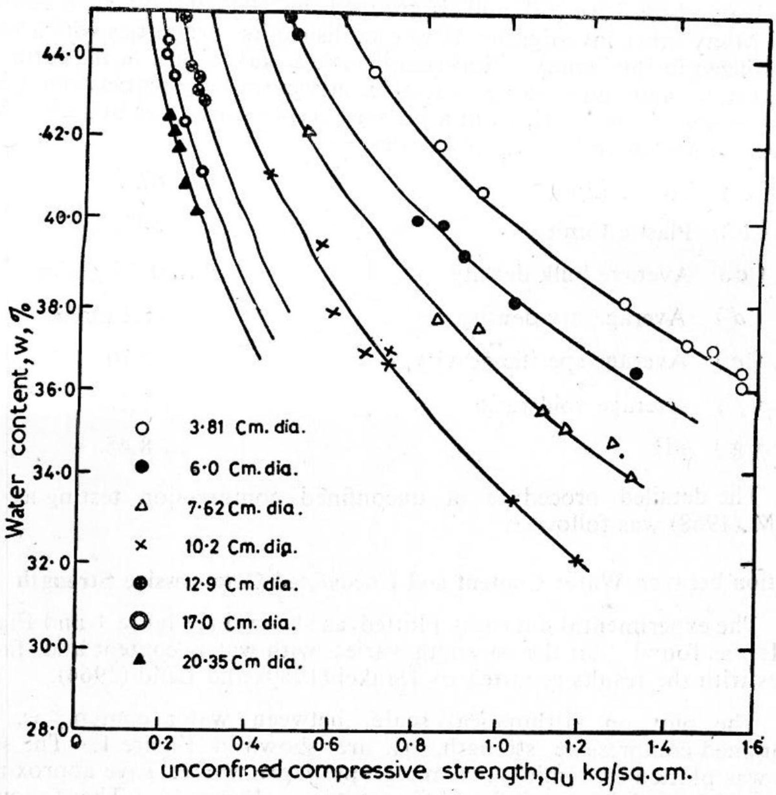

FIGURE 1 : Relationship between water content, unconfined compressive strength and diameter.

The average value of the slope was found to be equal to —0.192.

The values of parameter, N, varied with change in specimen size. Hence, it became necessary to determine a suitable relation between the diameter and the parameter, N. On a semi-log plot (Figure 3) the values of diameter, D, and parameter, N, gave straight line relationship of the type given below :—

$$N = m \text{ Log}^{D+C} \quad \dots (2)$$

Again, using the least squares mothod values of slope, m, and constant, C, were determined. The values thus obtained are m=—0.163 and C=0.502.

Correlation between q_u, w and D

Combining Equations (1) and (2) and putting values of M, and C, following result was obtained :—

$$\text{Log } q_u = \frac{1}{0.192}(0.502 - w - 0.163 \text{ Log } D)$$

$$= 0.52\,(0.502 - w - 0.163 \text{ Log } D) \quad \dots (3)$$

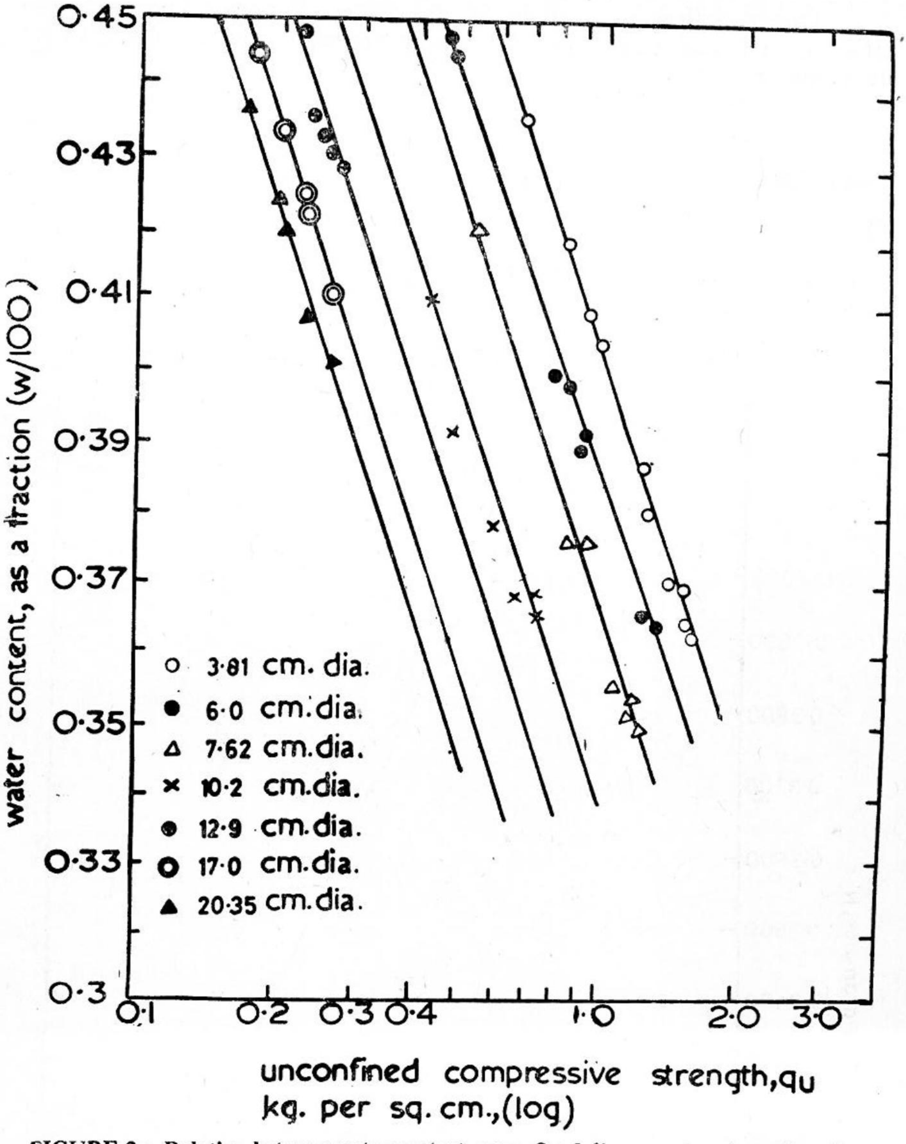

FIGURE 2 : Relation between water content, unconfined Compressive strength and diameter of specimen:

The empirical relation gives the desired correlation among the unconfined compressives trengh, q_u, water content, w, and specimen diameter D, with following units :—

(*a*) The unconfined compressive strength, q_u, in kilogram per square centimeter.

(*b*) The natural water content, w, as a fraction.

(*c*) Diameter of the specimen, D, in centimetres.

This equation gave error of the order of 5 to 15 percent. In strength studies of this nature this amount of error was considerd to be unavoidable.

Discussion

THE relation between values of the strength and water content is shown in Figure 2. It was clearly indicated that, as the specimen diameter increases the unconfined compressive strength decreases for a given water content. This may be explained as under :—

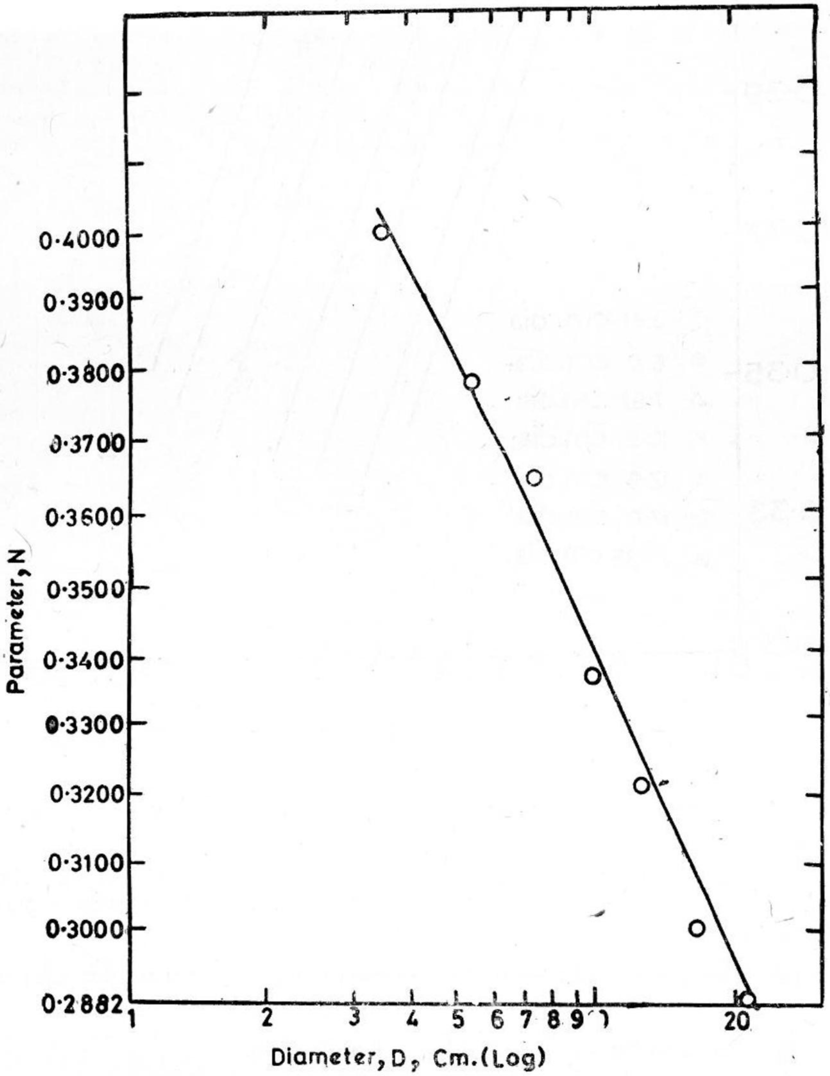

FIGURE 3 : Relation between parameter and diameter.

(a) *Discontinuities* : Slightly over-consolidated soils usually have numerous cracks, and over-consolidated soils have slickensides and fissures randomly scattered. These surfaces of weakness subdivide the specimen into small fragments. Also, during excavation the confining stresses are reduced causing expansion of the clay, and some fissures may open. Unequal swelling produces new fissures until the larger chunks disintegrate, and the mass is transformed into a soft matrix (Terzaghi and Peck 1967).

If a specimen is small, it is quite possible that such failure causing elements may be fewer in number or may be completely absent and thus the measured strength is higher as compared to that of a larger specimen, which would probably contain larger number of hair cracks or fissures.

(*b*) *Volume Changes* : Soil swells, when it is taken out from the ground, as a result of the reduction of external stresses. This indicates the possibility of the gradual reduction of the internal stresses by internal swelling. Due to this phenomenon migration of pore-water from outer zones of specimen to the interior would cause swelling and thus decrease the shear strength (Taylor 1964). Greater the specimen more pronounced would be this influence.

(*c*) *Surface Energy* : Migration of pore-water from outer zones to the interior of a specimen signifies expenditure of surface energy. The external energy expended during a volume increase may in part be supplied by internal swelling pressures and may involve a decrease defined by Bishop (1950), and primarily changes the angle of shear strength (Hvorslev 1960). Thus the bigger specimen will show lesser strength than the smaller specimen.

(*d*) *Reorientation of Stresses* : Both anisotropy and reorientation of the principal stresses may cause variation of the undrained strength of clay (with orientation of the failure plane, Duncan and Seed 1966). The assumption of isotropy in strength theories is closer to small specimens than to large ones.

(*e*) *Disturbance* : Small sized specimen are likely to be densified during the driving and extracting operation due to friction between sampling tube and the sample. If large sized specimens are cut out of a block of soil no such densification is involved. This clearly indicates that the strength obtained from unconfined compressive tests on smaller tube specimens give higher values than that on larger specimens.

Conclusion

The following conclusions may be tentatively drawn from this study :—

(*a*) There exists a unique relationship between strength of cohesive soil measured in unconfined compression testing and the water content of the specimen at failure.

(*b*) The unconfined compressive strength decreases with increase in the specimen size, at given water content. The study further strengthens the indication that some relation must exist between the size and strength. For the sizes of specimens used in this study the relation between measured compressive strength, q_u, water content w and specimen diameter D, may be expressed empirically as,

$$\text{Log } q_u = 5.2\,(0.502 - w - 0.163 \text{ Log } D)$$

(*c*) For the soil tested (CH), confirmatory testing has indicated that, if water content and diameter of the specimen were known, the unconfined compression strength of undisturbed samples could be reasonably predicted without resorting to actual testing.

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