Effect of Repeated Loading on the Shear Strength Parameters of C-ϕ Soil

by

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Introduction

The effect on the strength of soil due to the repetition of loads has been recognised since long. In this respect the cohesionless and cohesive soils are found to behave differently. As the change in strength due to repetition of load is considerable, the subject has assumed importance. It appears that the pattern of repeated loading is an important factor effecting the strength of the soil. Depending upon the pattern of loading the strength may either increase or decrease. Under certain conditions of very quick repetitions the soil may fail at considerable lower loads. The repeated loading occurs in following practical cases e.g. on highways, runways, railways, subways, bridge foundations, action of compactors and drawdown in earth dams.

Review of literature

The time dependent nature of soil strength was for the first time indicated by Collin (1958). He defined two types of strength of soil as "Instantaneous Soil Strength" and "Permanent Soil Strength". Using a special shear device Collin observed that the permanent strength of clay may be in the range of 24 to 34 per cent of instantaneous strength.

Taylor (1947), investigated the strength of a clay that was remoulded at liquid limit and then consolidated under 4.22 kg/cm^2. In these tests the strength of specimens that were loaded to failure quickly was found to be about 25 per cent greater than the strength of specimen that were loaded slowly.

Casagrande and Shannon (1948*a* and 1948*b*) found that the strength of clay and shale loaded to failure in about 0.02 Sec. was found to be between 1.5 to 2.0 times greater than their 10 minutes static strength.

Whitman and Taylor (1952, 1953, 1954), carried out a series of tests at M.I.T. on the behaviour of soil under dynamic loading. These studies have generally shown an increase in soil strength. For dry sand this increase has been of the order of 10-30 per cent over a range of loading times 10 minutes to 0.01 sec.

Seed and Lundgren (1954), have stated that strength of dense saturated sand tested in triaxial compression under transient loading conditions is greater than for normal rates of loading.

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This paper was received in April 1979 and is open for discussion till the end of January, 1981.

In a subsequent publication Seed (1959) and others have reported the results of tests on silty clay. The specimen was subjected to a confining pressure of 14.2 psi. An additional axial stress of 9.9 psi was then applied to the specimen for a period of 0.33 sec. After a period 2.7 sec the same stress was again applied for the same period of time. This procedure was repeated 100000 times.

It was found that a series of stress applications to a compacted clay may produce a considerable stiffening effect in the clay and a consequent increase in resistance to deformation.

Ahmad and Larew (1962), have reported that unstabilised samples of micacious silt generally did not fail until subjected to repeated load of magnitudes equal to or greater than 95 per cent of ultimate gradually applied load, even though many thousands of these load repetitions were applied.

Schimming and others (1966), developed a direct shear device and carried out tests on various types of soils. They defined two types of tests viz., Rapid static tests and Dynamic test and determined the variation of cohesion ratio defined as

$$\text{Cohesion ratio} = \frac{(C_a)\ \text{dynamic}}{(C_a)\ \text{Static.}}$$

They concluded that cohesive $C-\phi$ soils exhibit an increase in apparent cohesion.

Similar studies were carried out by Seed et al (1967, 1966)

Theory

The usual expression for the strength S of the soil is

$$S = C + \sigma \tan \phi \qquad \ldots(1)$$

Where C is the cohesion, ϕ the angle of internal friction of the soil and σ is the normal stress.

The values of C and ϕ are expected to change under repeated load. If C_r and ϕ_r are the Cohesion and angle of internal friction respectively under repeated load, then the shear strength S_r of the soil under repeated load is given by

$$S_r = C_r + \sigma \tan \phi_r \qquad \ldots(2)$$

Let C_0 and ϕ_0 represent the cohesion and angle of internal friction for the case of no repetition of load. Then the strength s_r under repeated load can be expressed in terms of C_0 and ϕ_0 by introducing two parameters, cohesion ratio, a, and friction angle ratio, b, as follows,

$$a = \frac{C_r}{C_0} \quad b = \frac{\phi_r}{\phi_0} \qquad \ldots(3)$$

so that $$C_r = a\, C_0 \quad \phi_r = b\phi_0 \qquad \ldots(4)$$

Then S_r can be expressed in terms of C_0 and ϕ_0 as

$$S_r = a\, C_0 + \sigma \tan (b\, \phi_0) \qquad \ldots(5)$$

The values of C_0 and ϕ_0 will be constant for a soil as they refer to the case of no repetition. The values of, a, and, b will change according to the pattern of repeated load.

Pattern of repeated load

Repetition of load can occur in various patterns. Several patterns of repetition of loads can be visualised as graphs between time and the intensity of repeated load. Each pattern in general is constituted of the following variables.

Intensity of repeated load *I*

This is the value of the load repeatedly applied on the sample. In the present case it has been expressed as percentage of the failure load with no repetition.

Cycle time T

This is the total time of one loading and one unloading operation.

Number of repetitions N

This is the number of times by which the load is repeated over the sample.

The pattern of repeated load used in the present work is shown in Figure 1. where the above mentioned terms are defined.

In the present study the variation of, a, and, b with respect to variables I, T and N was determined.

Description of soil

The soil used in the present study was obtained from the foundation trenches of a building at Aligarh Muslim University Campus. The particle size distribution of the soil is shown in Figure 2. The liquid limit and plastic limit of the soil are 32 and 15 per cent respectively.

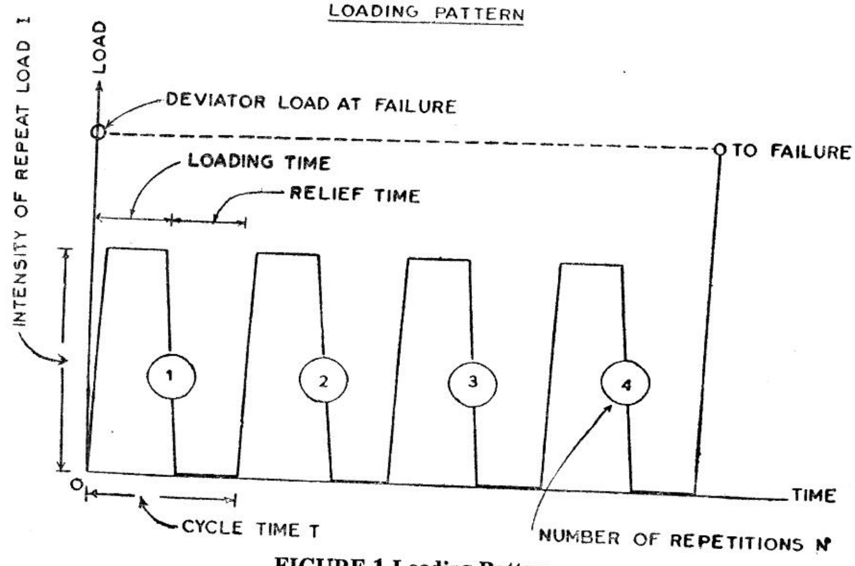

FIGURE 1 Loading Pattern

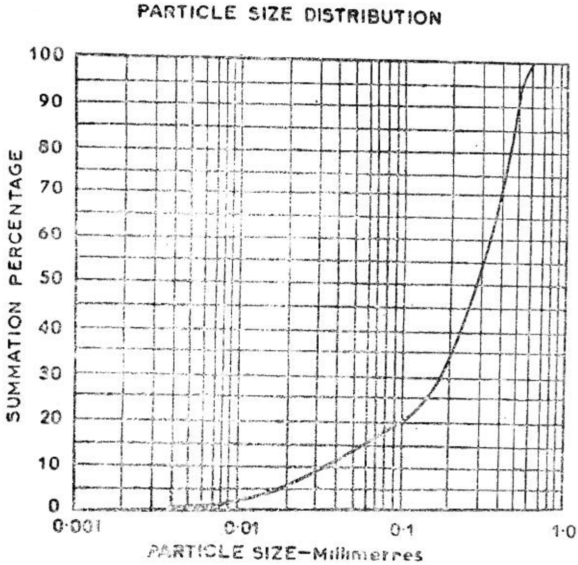

FIGURE 2 Particle size distribution

Completely saturated cylindrical samples of 3.81 cms (1.5″) diameter and 7.62 cms (3″) long were prepared at a unit weight of 2.04. The degree of saturation varied from 95 to 100 per cent.

Method of Testing

The tests were carried out in a triaxial cell suitable for standard sample of 3.81 cms. (1.5″) diameter and 7.62 cms. (3″) long. The loading were affected by the help of a loading frame. The loads were measured by the help of high sensitivity proving ring. All these tests were carried out on completely saturated samples under undrained condition. The rate of load application was kept same in all the tests.

Three series of tests were carried out. In each series first the deviator failure load was determined by testing a sample without any repetition of load. Then several samples were tested with the loading pattern given in Figure 1. The intensity of deviator load repeated I is expressed as *percentage of deviator failure load with no repetition.* The repeated deviator loads used were 25, 50 and 75 per cent of deviator load at failure for the case of no repetition. The cyclic time T used was 120, 240, 600 secs. The loading time and relief time was kept equal. The number of repetitions N applied were 5, 10, 15 and 25. All possible combinations of the values of I, T, and N indicated above were used with confining pressures of zero, 0.703 kg/cm^2 (10 Psi) and 1.406 kg/cm^2 (20 psi).

First, tests were carried out at zero, 0.703 and 1.406 kg/cm^2 confining pressures to find the values of deviator load at failure in the case of no repetition. From these three readings the Mohr failure envelope corresponding to the case of no repetition was obtained. From this envelope the shear strength parameters C_o and ϕ_o corresponding to the case of no repetition of load were obtained.

The several samples were tested under repeated loadings. As an example the test with 0.703 kg/cm^2 confining pressure and $I = 50\%$,

$T = 600$ secs and $N = 5$ was carried out as follows. A sample was set under a confining pressure of 0.703 Kg/cm². 50 per cent of the deviator load (obtained in case of no repetition), was then applied to the sample. The sample was kept loaded at this load for 300 secs, after which the load was released. The sample was then left unloaded for 300 secs. At the end of this relief period the sample has completed one load cycle. In all five such cycles were repeated to complete five number of repetitions. At the end of relief period of the 5th cycle the specimen was loaded to failure. The deviator load at failure for repeated load was noted.

Test with same values of I, T, and N were then carried out with zero, and 1.406 Kg/cm² confining pressures. These three readings give the Mohr failure envelope and C_r and ϕ_r and they correspond to $I = 50'\%$, $T = 600$ secs and $N = 5$. The cohesion ratio, a, and the friction angle ratio, b, were then calculated as

$$a = C_r/C_o \qquad b = \phi_r/\phi_o$$

Values of, a, and, b, were determined for all possible combinations of the values of I, T and N used. The value of, a, and, b, are plotted against I, T and N.

Discussion of Results

Nature of Failure :

The failure in general is by bulging in the middle. Small longitudinal cracks develop on the cylindrical surface. Near the ends due to some restrain offered by the perspex discs there is no bulging. Therefore the stress at failure generally does not remain uniform throughout the body of sample. In most of the cases hard rings are developed at the ends of the cylindrical specimen. As the strain increases the difference between the length of the rubbersheath and that of the specimen increases. This results in the development of several ring like fold in the sheath. Under the action of confining pressure it produces a screw-like pattern on the surface of the cylinder in the middle portion of the sample. The effect of this penetration is the hardening of the surface of the sample.

The plane of slip appears clearly only in cases of zero confining pressure. The slope of the failure plane with the major principal plane varies from 53° to 57°.

Variation of, a, with T, N, I

The cohesion of the soil is increased by the repeated loading. The maximum and the minimum increase in the value of, a, obtained are 2.00 and 1.43. Mean value of, a, is 1.76 with a standard deviation of 0.137.

Effect of I

The variation of a, with respect to I only is not great (Figure 3). With large number of repetitions, the value of, a, tends to decrease with increasing I. For smaller number of repetitions the value of, a, increases with I. With low values of cycle time the trend is an increase in, a, with increase of I. Most of the curves either flatten or go downward as higher values of I are approached.

Effect of N

The value of, a increases with number of repetitions but after large number of repetitions the curves become flatter and approach nearly a constant value (Figure 4). This may be due to the completion of compaction process. High I- values tend to decrease the value of, a,. Similarly long duration of cycle time produces a fatigue effect and reduces the value of, a. However curves for $T = 240$ secs, $I = 25\%$ and $T = 600$ sec $I = 25\%$ exhibit a slightly different trend as they do not flatten out even

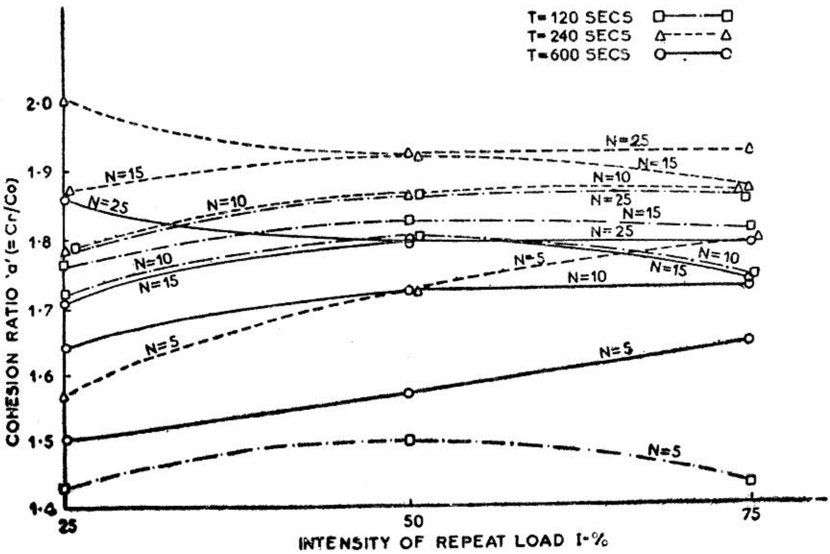

FIGURE 3 **Variation of cohesion ratio with the intensity of repeated load *I*.**

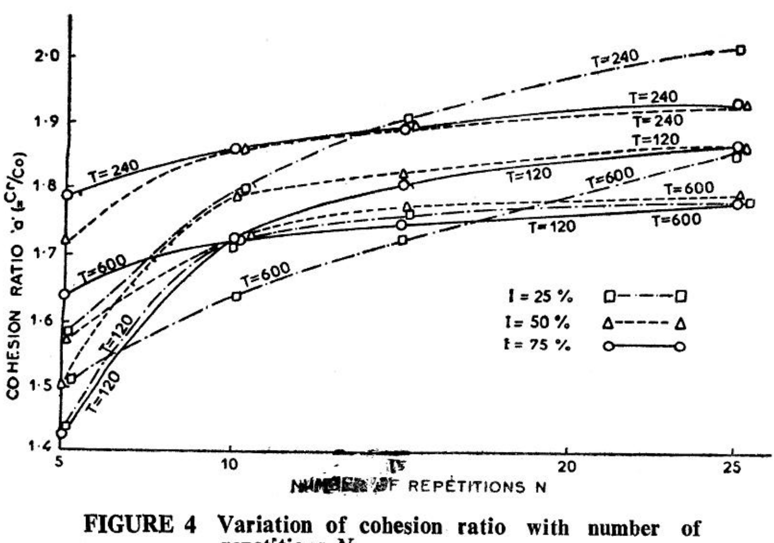

FIGURE 4 **Variation of cohesion ratio with number of repetitions *N*.**

upto $N = 25$. In those cases as I is 25% the process of compaction may have not been completed in 25 repetitions. It is excepted that the curves will flatten at some higher value of N.

Effect of T

All the curves show an initial sharp rise and then after attaining a maximum value of, a, sharp fall observed (Figure 5). This is indicative of the dominating effect of the fatigue. Higher values of, a, are obtained for large number of repetitions and low intensities of loads.

Variation of b with T.N.I.

Generally the value of, b, is found to decrease. Only in few cases it increases beyond 1.0, b, varies from a value of 0.74 to 1.05. Mean value of, b, is 0.899 wtih a standard deviation of 0.107. (Figures 6, 7 and 8).

Effect of I

The variation of, b, with I is somewhat complex (Figure 6). For low values of cycle time T the lowest value of, b, is obtained at about 50 per cent of I, after which the value of, b, again increases. For large values of cycle time the value of, b, increases with large number of repetitions.

Effect of N

Both increasing and decreasing trends are noticed under various conditions (Figure 7). For low value of cycle time the value of, b, increases with number of repetitions. For high values of cycle time, b, decreases with number of repetitions. For lower values of intensity of repeated load and cycle time the increase in, b, observed is highest.

Effect of T

Both increasing and decreasing trends are noticed under various conditions (Figure 8). For lower values of number of repetitions the value

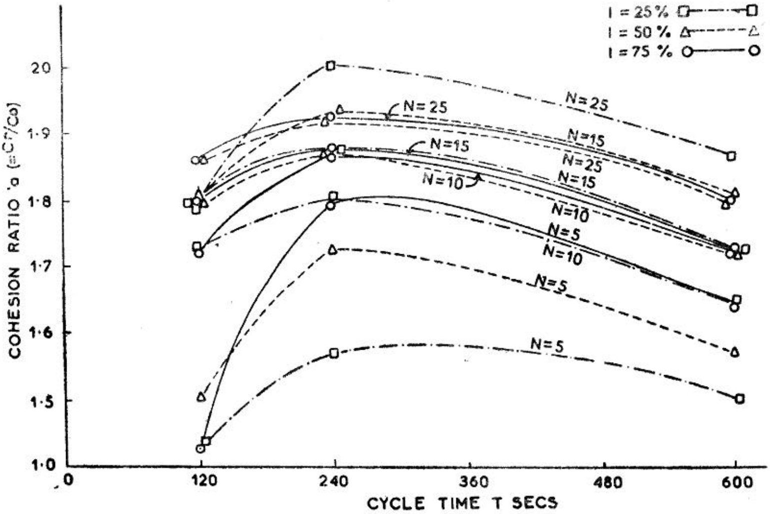

FIGURE 5 Variation of cohesion ratio with Cycle Time.

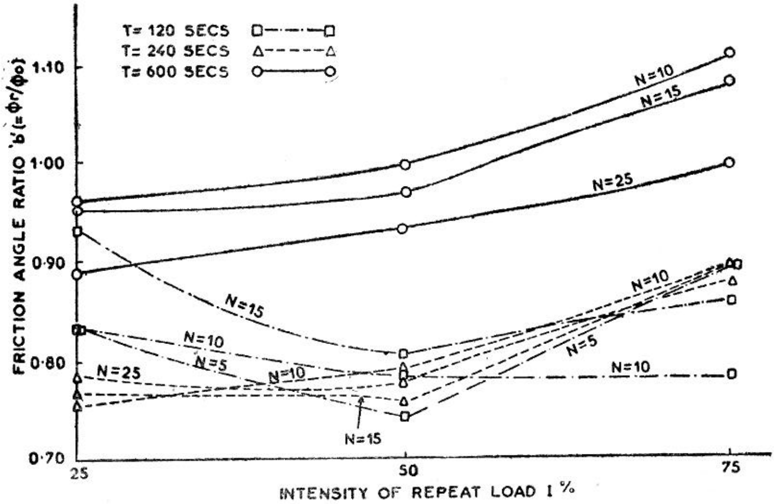

FIGURE 6 Variation of friction angle ratio with intensity of repeated load *I*.

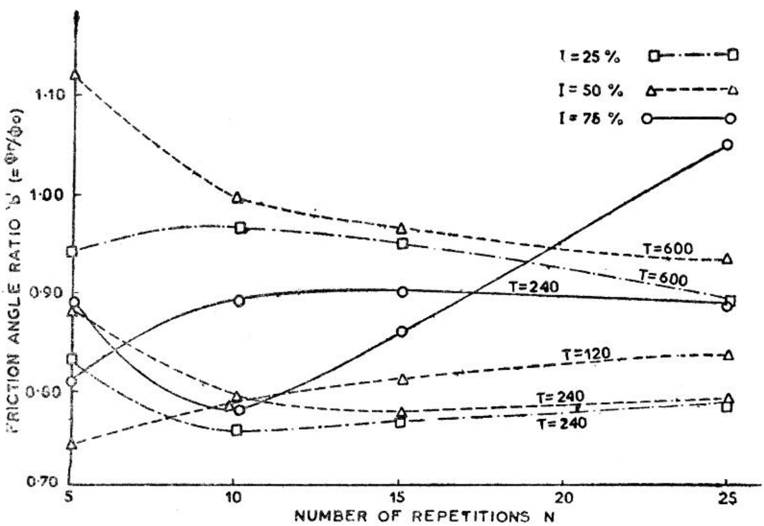

FIGURE 7 Variation of friction angle ratio with the number of repetitions *N*

of, *b*, increases with increases in cycle time. For low values of repeated load the value of, *b*, initially decreases and then starts increasing with increase in cycle time.

Comparison with Results of other Investigators

A comparison of the results obtained in the present work with the work of other researchers is given in Table I prepared along the lines suggested by Schimming (1966). The, *a*, values are in fairly close agreement with those obtained by other investigators. However there are significant differences in the *b*- values as other researchers have assumed ϕ_r as constant.

TABLE 1

Summary of Repeated Load Test Results on Cohesive Soil

Name of Author and Year	Casagrande and Shanonn 3, 4, 1948	Taylor and whiteman 6, 7 1954-55	Whiteman and others 5 1962	Kane and others	SCHIMMING AND OTHERS 1966						Present Study
Soil used	Clay	Clay	Clay	Clay	Jordan Buff Clay Compacted	Western Beatonite. Clay Compacted.	Chicago Blue Clay Un-disturbed.	Jordan Buff Clay + Sand $C=\phi$	Rechester. Sandy Silt Un-disturbed	Notre Dam Lake Mart Un-disturbed.	$C-\phi$ Soil
Test type	Unconfined and Triaxial compression.	Unconfined and Triaxial Compression	Triaxial compression	Triaxial compression.	......Direct Shear......						......
Confining Pressure Normal stresss kg/cm²	3,6	2.12.9 and 5.9.	4.2	8 to 71	......Direct Shear......						0,0.703 and 1.406
Rise time used Seces.	0.01 to 600	0.005 to 300	0.0015 to 100	0.003 to 100							
Cycle Time T-Secs-											*120,240 and 600
Number of Repetitions											5, 10,15, 25

(*Contd.*)

Intensity of repeated load 1%.											25, 50, 75
C_o kg/cm²					0.630	0.200	0.364	0.490	0.476	0.343	0.140
ϕ_o degree					4	0	0	15	38.5	20.5	13.5
C_r kg/Cm²					1.575	3.700	0.619	0.980	1.024	0.481—.	0 20 to 0,28
ϕ_r degree					4	0	0	15	35.5	20.5	10 to 14.2
$a = C_r/C_o$	1.5 to 2.0	1,3 to 2.0	1.57 to 1.71	1.5	2.5	1.85	1.7	2.0	2.15	1.4	1.43 to 2.0
$b = \phi_r, \phi_o$									Not calculated		0.74 to 1.05.
Remarks	(..........Value of "a" mentioned...... as increase in strength....................)								$b = \phi_r/\phi_o$ $= 35.5/38.5$ $= 0.922$ but not taken note of.		

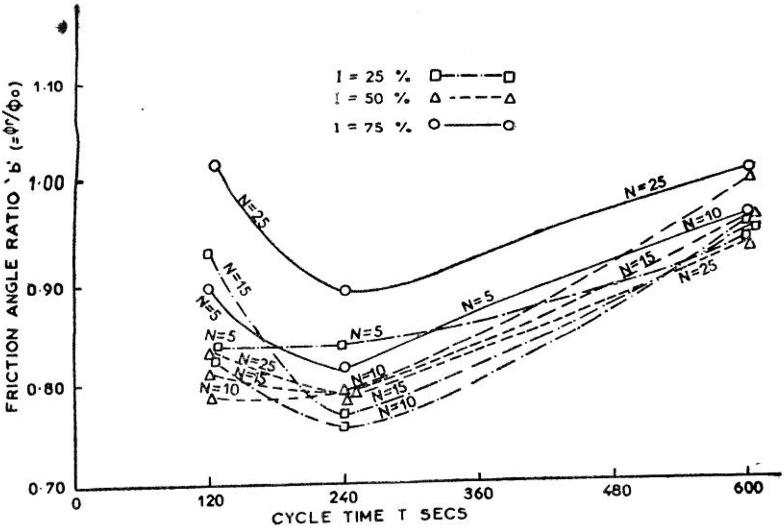

FIGURE 8 Variation of friction angle ratio with the cycle Time *I*

Conclusions

Within the range of testing and for the pattern of repeated load adopted the following conclusions can be obtained.

(*i*) The value of, *a*, always increases with repetitions of the load and the increase is up to 100 per cent under certain conditions, *a*, varies from 1.43 to 2.00. Mean value of, *a*, is 1.76 with a standard deviation of 0.137. Very high values of *I* combined with large number of repetitions results in lower value of, *a*.

(*ii*) *a*, increases with number of repetitions but approaches a constant values.

(*iii*) For small values of cycle time, *a*, increases but starts decreasing as cycle time increases.

(*iv*) Generally, *b*, is found to decrease with the repeated load, *b*, varies from 0.76 to 1.15. *b* has a mean value of 0.899 with a standard deviation of 0.107.

(*v*) For low values of *I* and *T* increase in *b* is highest.

(*vi*) Since the increase in C_r is large as compared to decrease in ϕ_r the overall effect of repeated load is increased strength of the soil, except in case of very high normal stress.

Acknowledgements

The authors are greatful to late Dr. J.P. Singhal of Chemistry Section of Applied Science Department of Zakir Husain College of Engineering and Technology, Aligarh Muslim University, Aligarh for determining the grain size distribution. The authors are thankful to the Chairman, Department of Civil Engineering, Aligarh, Muslim University, Aligarh for providing all facilities for the work.

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Notations

a = Cohesion Ratio C_r/C_0

b = Friction Angle Ratio ϕ_r/ϕ_0

c = Cohesion of Soil

C_0 = Cohesion of the soil with no repetition of load.

C_r = Cohesion of the soil in repeated load test.

I = Intensity of Repeated Load.

N = Number of Repetitions

s = Shear strength of the soil

s_r = Shear strength of the soil in repeated load test.

T = Cycle Time.

ϕ = Angle of Internal Friction of the Soil

ϕ_0 = Angle of Internal Friction of the Soil in case of no repetition.

ϕ_r = Angle of Internal Friction of the Soil in repeated load test.

σ = Normal Stress.