Effects of Repeated Loads on Elastic Micaceous Soils Stabilized with Portland Cement

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The results of a laboratory study of the effects of repeated load triaxial tests on the stress-deformation characteristics and resilient properties of two elastic micaceous soils stabilized with portland cement are discussed. The ultimate strength and stress-deformation curves for both untreated and cement-treated soils are reported for both conventional and repeated triaxial loadings. The addition of proper amounts of portland cement to these soils greatly increases the strength and stiffness and considerably reduces the resilience. However, the strength and stiffness of these cement-treated soils under the action of repeated loads are not always properly represented by the results of a conventional (gradually applied load) triaxial test. Both the ultimate strength and stiffness of cement-treated soils are less when obtained in a repeated load test. The elastic rebound or resiliency for both untreated and cement-treated soils appears to be directly and perhaps uniquely related to the ratio of the applied repeated deviator stress to the compressive strength as determined in a conventional triaxial test.

•UNTIL A decade or so ago, highway engineers dealing with soil problems involving repeated or dynamic loadings were limited by lack of available information to use of static and gradually applied load parameters. Recent investigations have provided some basic repeated load information and have indicated, for example, that a soil may exhibit different strength-deformation properties when subjected to a series of repeated loads than it would when subjected to statically or gradually applied loads. Most of these studies have been concerned with compacted but untreated soils. Very little work has been reported on the effects of repeated loads on the strength and deformation characteristics of chemically stabilized soils.

Recently, Tate (1) stabilized and compacted a number of samples of a micaceous silt with 5 and 10 percent portland cement and allowed them to cure for 6 days. After testing identical samples under both repeated and gradually applied loads, he found that, except at low levels of deviator stress (approximately 50 to 60 percent or less of the ultimate gradually applied load), the samples would fail suddenly in shear after relatively few repetitions of load. As reported by Ahmed and Larew (2), unstabilized samples of the same type of soil generally did not fail until subjected to repeated loads of magnitudes equal to and greater than 95 percent of the ultimate gradually applied load, even though many thousands of these load repetitions were applied.

Tate also found that the magnitude of the elastic or resilient rebound for a given ratio of repeated load to ultimate gradually applied load was approximately the same for both stabilized and unstabilized soils.

Colley and Nowlen (3) reported studies in which they subjected granular soil-cement subbases to repeated loadings. The soil-cement subbases, 6 in. thick, were placed at AASHO standard density and optimum moisture directly below a rigid concrete slab.

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A load of 4,000 lb was transmitted to an 8-in. diameter steel plate resting on a rubber pad astride the joint in a concrete slab. Addition of cement to four granular subbase materials reduced the densification of these materials to an insignificant amount and eliminated pumping from two materials that had pumped before the addition of cement. Moreover, the use of soil-cement greatly reduced the pressure transmitted to the subgrade. These studies by Tate and the Portland Cement Association were the only known published works which dealt with laboratory studies of repeated loadings on stabilized soils.

Studies conducted by the California highway department (4) showed that highway pavements may fail by fatigue as a result of repeated reversals of stress. The fatigue failure is attributed in part to the resilient or elastic deformation of the subgrade underlying the pavement. Since much of the Piedmont Province of Virginia is covered with micaceous silty soils which are highly elastic or resilient and the Virginia Department of Highways has encountered difficulty in the use and performance of these materials, this study was undertaken to determine whether the treatment and stabilization of these soils with portland cement would improve their strength-deformation and resilient properties.

The two soils chosen for this study exhibited elastic properties and were obtained from the Piedmont Province of Virginia. The pedological classifications were Culpeper C and Glenelg C, and the AASHO classifications were A-2-4 and A-4, respectively. Index properties for these soils are listed in Table 1 and gradation curves are shown in Figure 1. Both Type I (normal) and Type III (high early strength) cements were employed in the study.

TABLE 1
BASIC SOIL INFORMATION

Soil Property	Glenelg C[a]	Culpeper C[b]
Fraction (% by wt.):		
Clay	7.5	4.0
Silt	53.5	22.0
Sand	39.0	74.0
Spec. gr. of solids	2.74	2.74
Shrinkage limit	24.5	28.50
Plastic limit	27.0	31.5
Liquid limit	35.0	32.0
0 pt. moisture content (%)[c]	21.5	18.5
0 pt. dry density (pcf)	98.5	99.2

[a]AASHO classification A-4.
[b]AASHO classification A-2-4.
[c]AASHO Designation: T99.

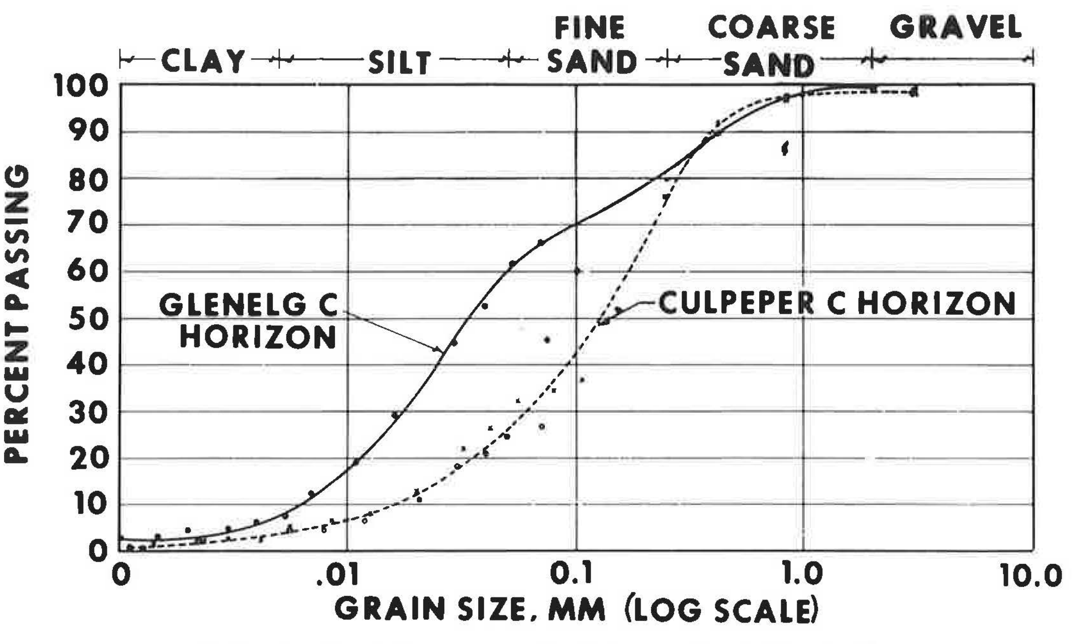

Figure 1. Gradation curves for Culpeper C and Glenelg C.

The purpose of this study was to determine the strength, deformation and resilient properties of these two stabilized soils under the action of repeated loads and to compare these with similar properties of the untreated soils.

SCOPE AND PROCEDURE

Studies were made to determine the required percentage of portland cement to be added to each soil so that Portland Cement Association requirements for soil-cement would be satisfied. For the Culpeper C, 10 percent of either Type I or Type III cement by ovendry weight provided the proper strength and durability for soil-cement. However, the percentage of portland cement required for the Glenelg C yielded sample strengths beyond the testing capability of the repeated load device and, therefore, a 5 percent mixture, which yielded a "cement-modified" soil, was used. All samples tested were compacted to optimum moisture and dry density in a Harvard miniature mold with a modified drop-type rammer. Each molded specimen of both cement-treated and untreated soils was protected by aluminum foil and wax, cured in a humid room at 68 F, and subsequently tested in either a conventional or repeated load triaxial device.

To reduce the curing time, Type III high early strength cement was used with both soils. A curing period of 10 days was employed for the Culpeper C soil. Figure 2 indicates that for this material there was only a minor strength gain after the 10-day curing period which minimized the effect of strength increase during the testing period. Figure 2 also indicates that the Culpeper C stabilized with Type I cement and cured for 35 days had essentially the same strength in the conventional triaxial test as the Type III cement-stabilized soil with a 10-day cure period. Figure 3 shows the similarity between conventional triaxial stress-strain curves for the Culpeper C stabilized with both types of cement, each type being cured for the previously mentioned lengths of time. Only a 5-day curing period at 68 F was required for the Glenelg C Type III cement-modified samples as shown in Figure 4. No Glenelg C Type I cement-modified samples were prepared.

Conventional and repeated load triaxial units as described by Larew and Leonards (5) were used to obtain the conventional and repeated load stress vs strain curves for both untreated and cement-treated soils. A confining pressure, σ_3, of 10 psi was used for all tests and most specimens were subjected to 100,000 load repetitions applied at the rate of 20 loads per minute. Both total deformation and elastic rebound deformation

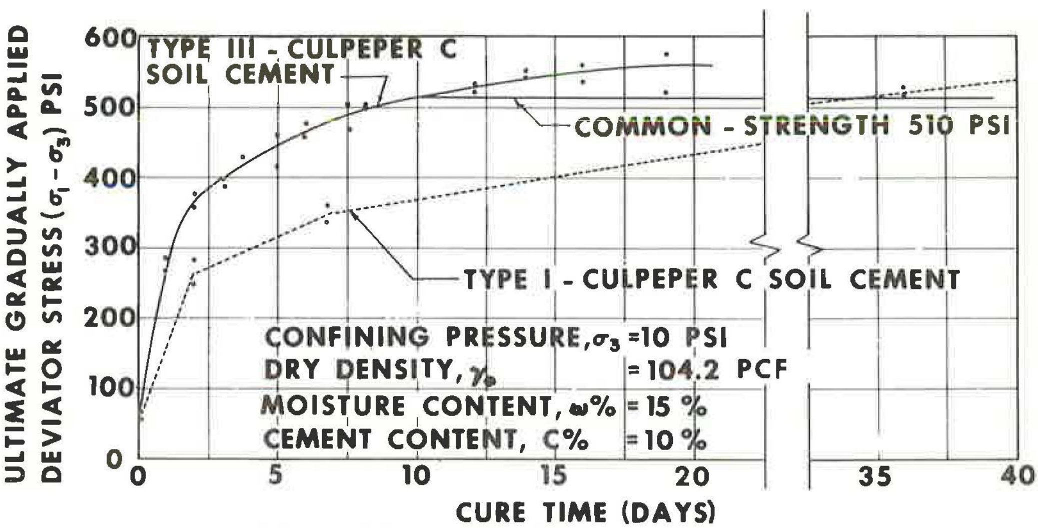

Figure 2. Ultimate gradually applied stress vs cure time for Type I and Type III cement.

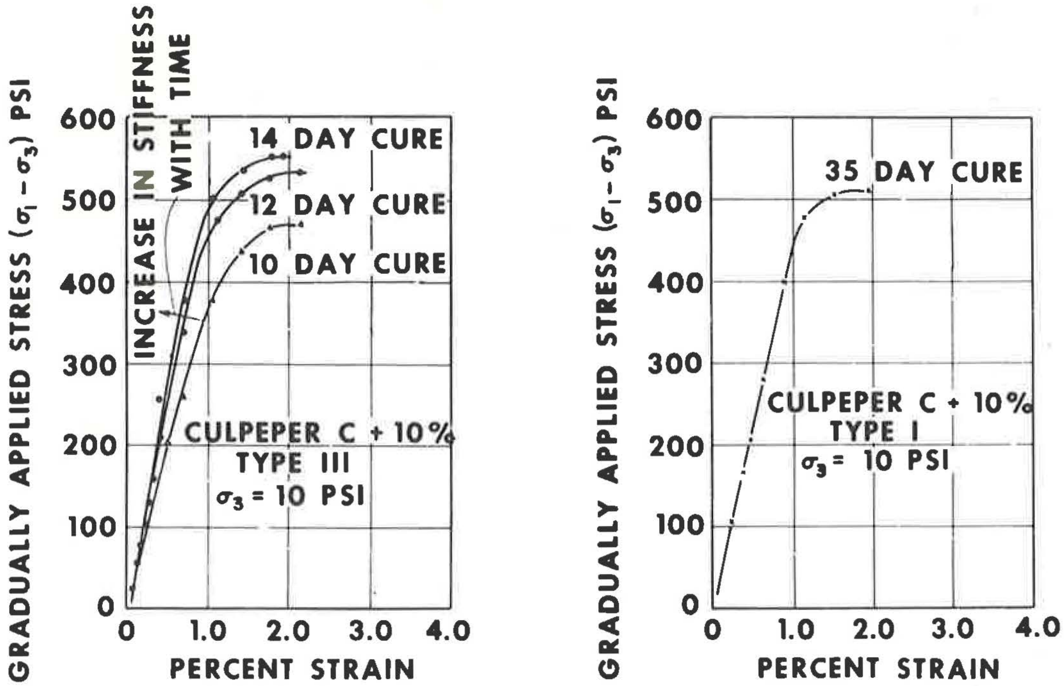

Figure 3. Comparison of conventional stress vs strain curves for Culpeper C + 10 percent Type III cement and Culpeper C + 10 percent Type I cement for various curing times.

readings were obtained for each sample tested in the repeated load device. A typical deformation vs log of the number of load repetitions curve is shown in Figure 5.

The repeated load stress vs strain curves were obtained by essentially the same method first described by Ahmed and Larew (2). As shown in Figure 5, the total

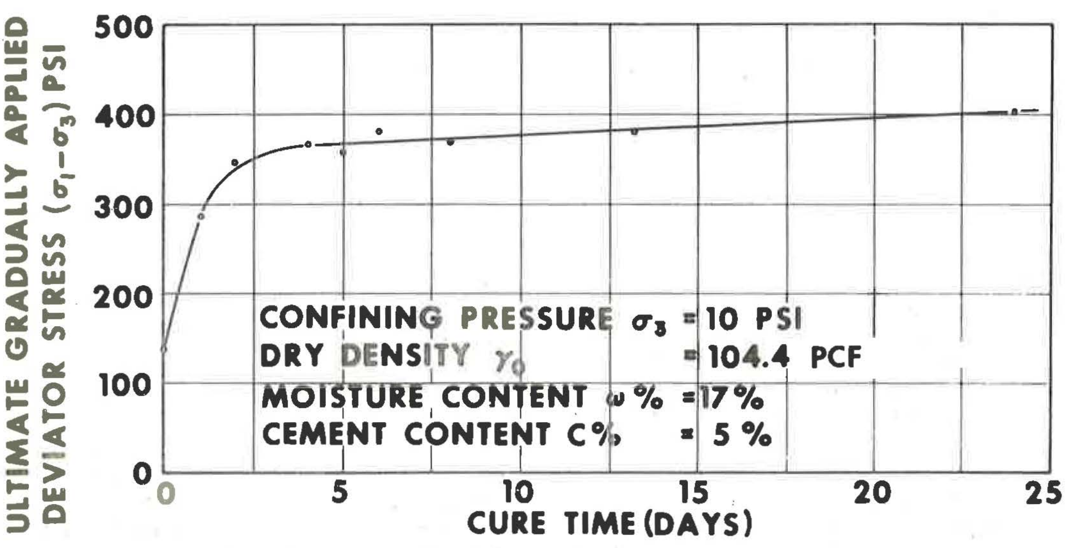

Figure 4. Strength vs curve time for Glenelg Type III cement-modified soil.

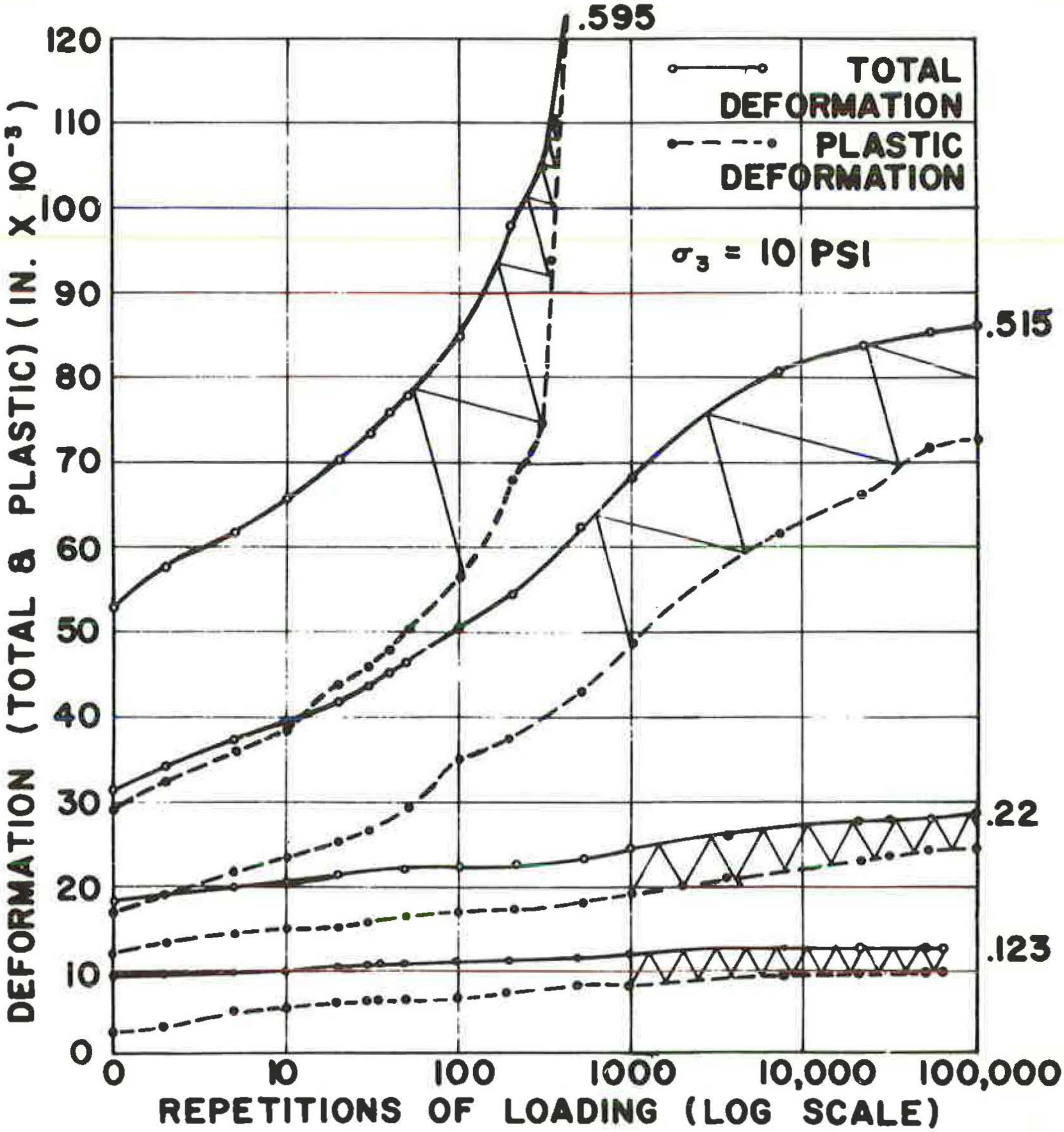

Figure 5. Repetitions of loading vs deformation for Glenelg C + 5 percent Type III cement; numbers to right are $\Delta\sigma_r/\Delta\sigma_s$ values.

sample deformation increased with each increase in the ratio of $\Delta\sigma_r/\Delta\sigma_s$. The term $\Delta\sigma_r/\Delta\sigma_s$ symbolizes the ratio of the stress induced by the magnitude of the repeated stress, $\Delta\sigma_r$, to the ultimate compressive stress, $\Delta\sigma_s$, as determined in the conventional triaxial test. For a given level of the ratio of $\Delta\sigma_r/\Delta\sigma_s$, the total deformation increased with increasing numbers of load repetitions, but at a decreasing rate. After a certain number of load applications, the total sample deformation became constant for each value of $\Delta\sigma_r/\Delta\sigma_s$ below a critical level of the ratio $\Delta\sigma_{rc}/\Delta\sigma_s$, as defined earlier by Larew and Leonards (5). For any level of $\Delta\sigma_r/\Delta\sigma_s$ in excess of this critical value, the sample deformation increased at an increasing rate with each additional load application until the sample failed. The limiting value of deformation for each level of $\Delta\sigma_r/\Delta\sigma_s$ below this critical value was defined as the equilibrium total deformation for that level of $\Delta\sigma_r/\Delta\sigma_s$. These equilibrium total deformation values were used by Ahmed and Larew (2) to calculate the corresponding sample strains. For very low ratios of $\Delta\sigma_r/\Delta\sigma_s$, such as 0.123, the equilibrium deformation was reached within a few hundred load applications in many cases. For ratios of $\Delta\sigma_r/\Delta\sigma_s$ above the critical level, no equilibrium deformation could be established, since the sample continued to deform until it failed.

From a family of curves such as that shown in Figure 5, several levels of $\Delta\sigma_r$ and the corresponding values of limiting strain were obtained. These data were then used by Ahmed and Larew to plot a repeated load stress-strain curve as shown in Figure 6. Both repeated and static load stress-strain curves shown in Figure 6 are for one level of dry unit weight and water content. From repeated load stress-strain curves such as these, static and repeated strength moduli, E_s and E_r, were calculated. The procedures for obtaining the repeated load stress-strain curves employed by the authors differed from the foregoing method in that the limiting total deformation for any level of repeated deviator stress, $\Delta\sigma_r$, was chosen at a constant and arbitrary number of load repetitions rather than for the equilibrium condition.

RESULTS

Families of curves similar to Figure 5 were obtained for Glenelg C stabilized with 5 percent Type III cement, for Culpeper C stabilized with both Type I and Type III cements, and for the untreated Culpeper C. The elastic deformation or resiliency at a point on any one curve is the vertical distance between the total and plastic deformation lines.

Figure 6 compares the stress-strain curve for the Glenelg C soil with 5 percent Type III cement as obtained in the conventional triaxial test with that obtained by

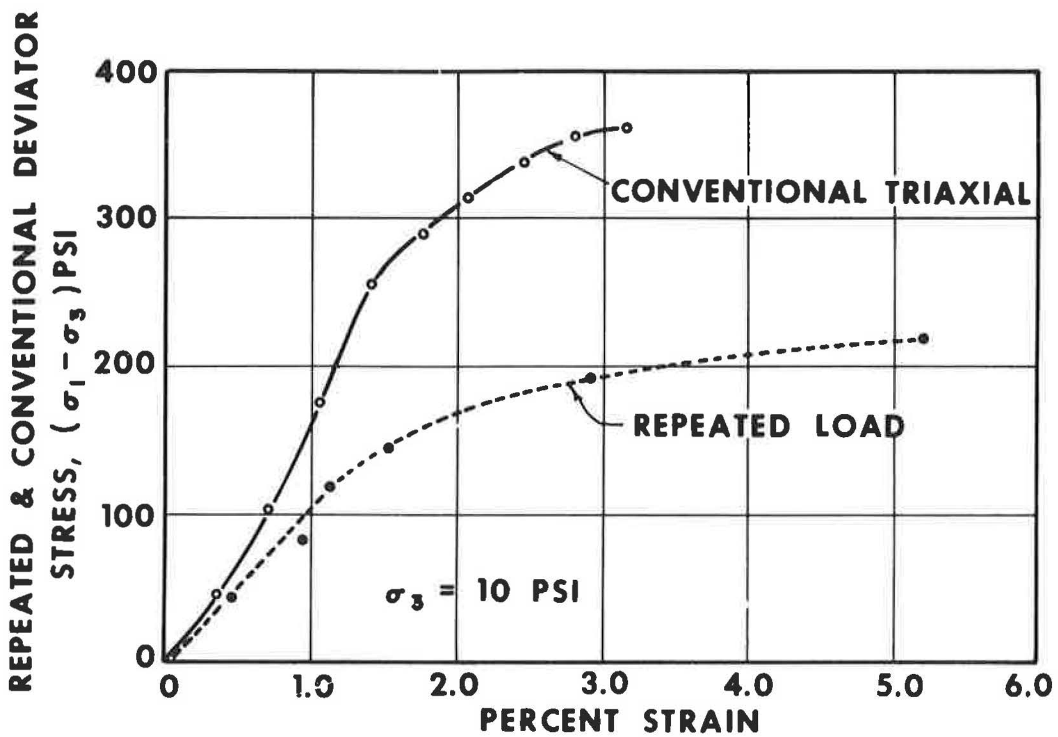

Figure 6. Repeated load and conventional stress vs strain curves for Glenelg C + 5 percent Type III cement.

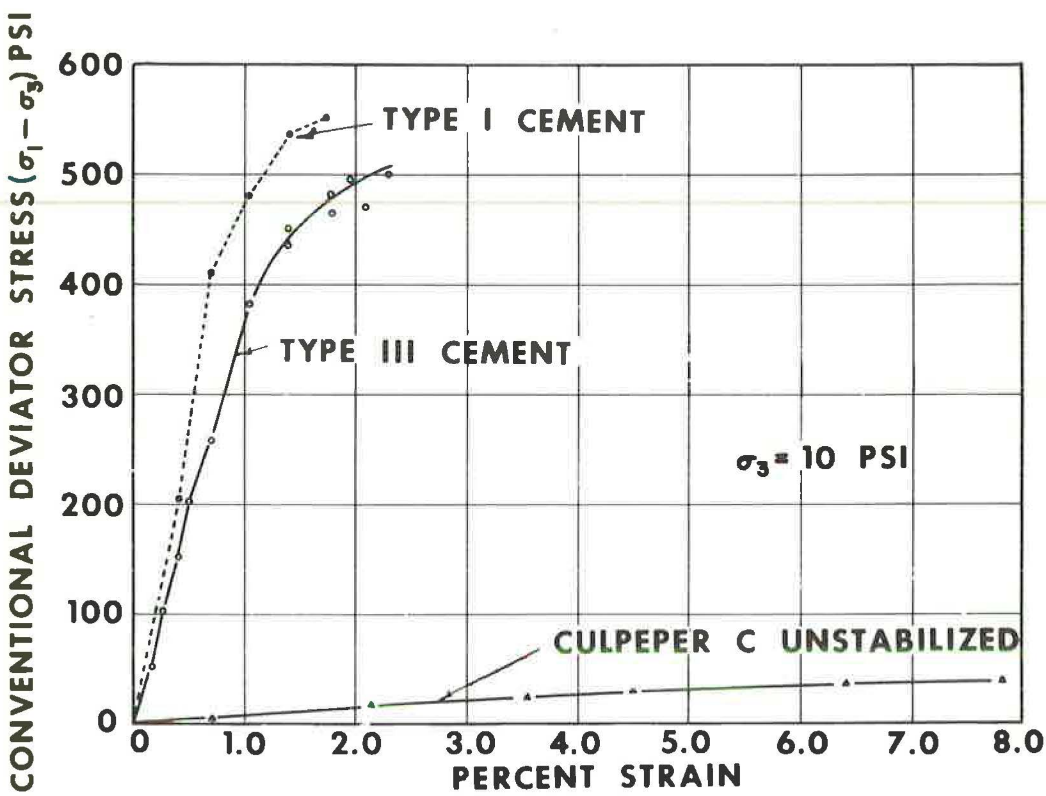

Figure 7. Conventional stress vs strain curves for unstabilized Culpeper C, Culpeper C + 10 percent Type I cement, and Culpeper C + 10 percent Type III cement.

repeated load triaxial tests. From Figure 6 it can be readily seen that the repeated load strength and stiffness for this cement-modified soil is considerably less for repeated loads than for conventionally applied loads; however, the strain at failure is essentially the same in both cases.

Figure 7 shows that the ultimate strengths and stiffnesses of the stabilized Culpeper C soil as obtained in the conventional triaxial test are much greater than that of the

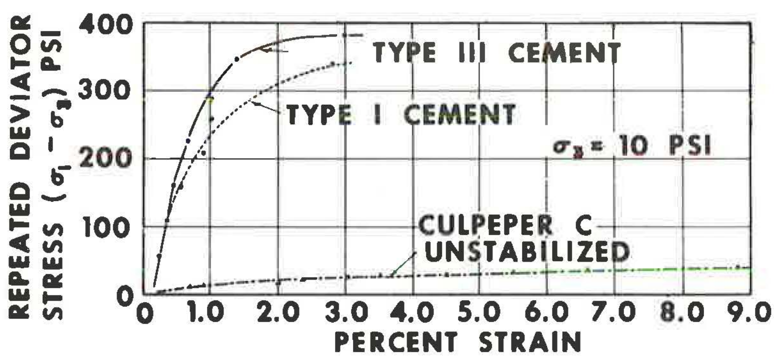

Figure 8. Comparison of repeated load stress vs strain for unstabilized Culpeper C, Culpeper C + 10 percent Type I, and Culpeper C + 10 percent Type III cement.

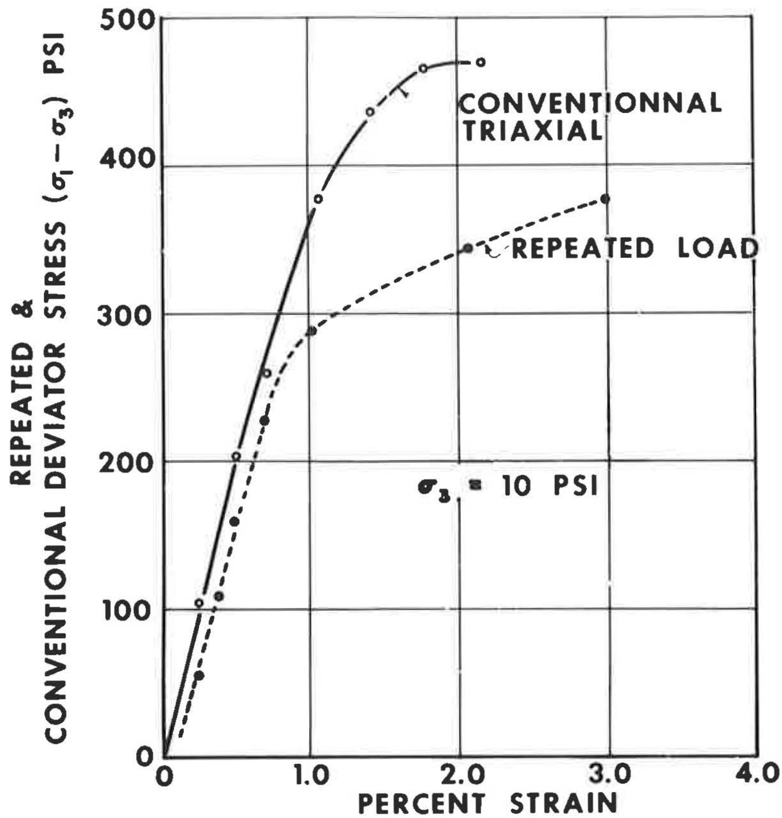

Figure 9. Repeated load and conventional stress vs strain curves for Culpeper C + 10 percent Type III cement.

unstabilized soil. Figure 8 shows the repeated load stress-strain curves for the Culpeper C soil, both untreated and stabilized with 10 percent Type I and Type III cements. Both ultimate strength and stiffness as obtained from repeated load tests are greater for the stabilized soil than for the unstabilized condition.

Figures 9 and 10 show a comparison of the conventional and repeated load stress-strain curves for the Culpeper C soil stabilized with 10 percent Type III and Type I cements, respectively. In contrast to the Glenelg C soil, the initial stiffness of the Culpeper C soil, as measured by an initial tangent modulus and as obtained from the repeated load stress-strain curves, is essentially the same as obtained in the conventional triaxial test. However, the ultimate strength of the Culpeper C soil, as obtained in the repeated load test, is less than that obtained in the conventional test.

Figure 11 is a comparison of the conventional and repeated load stress-strain curves for the untreated Culpeper C soil. In this instance the secant modulus for the repeated stress-strain curve is, at least, equal or greater than the conventional secant modulus. This is not in agreement with the findings of Ahmed and Larew (2) who, for untreated soils, obtained secant moduli in conventional triaxial tests that were always greater than the corresponding repeated load moduli. Differences in the manner of selecting equilibrium deformations from the deformation vs log of number of repetitions curves have caused this apparent disagreement with Ahmed and Larew's results, as explained earlier.

Figure 12 shows the variation of the equilibrium elastic rebound with changing values of the ratio $\Delta\sigma_r/\Delta\sigma_s$, where $\Delta\sigma_r$ is the intensity of the repeated deviator stress and $\Delta\sigma_s$ is the ultimate compressive strength as obtained in a conventional loading

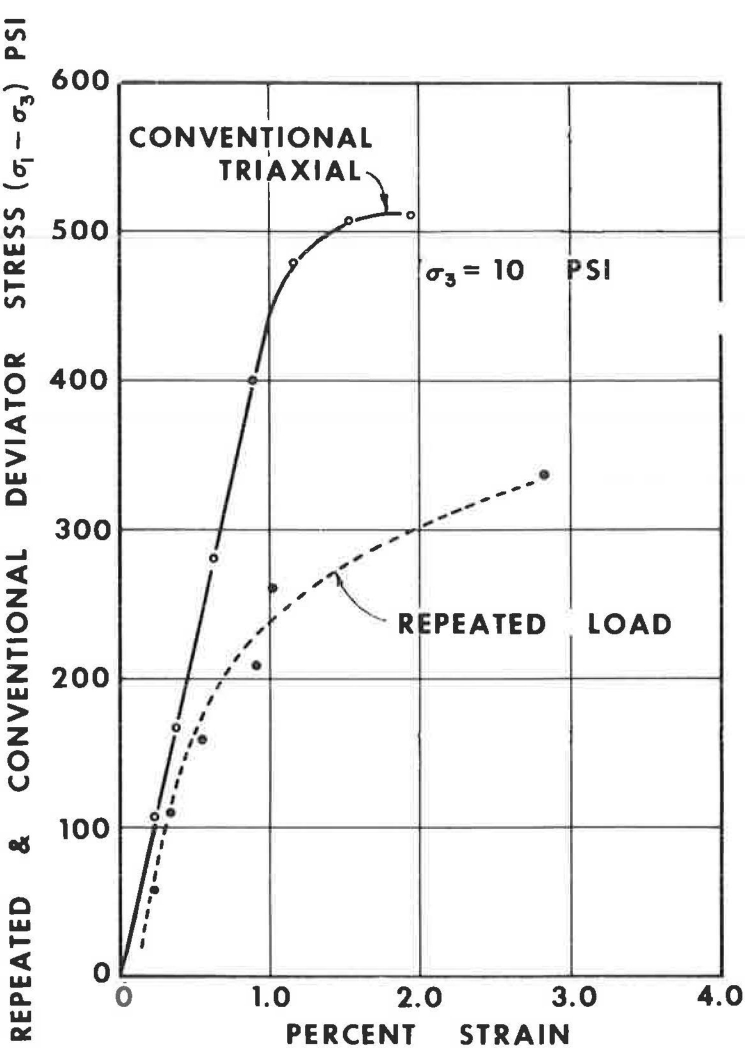

Figure 10. Repeated load and conventional stress vs strain curves for Culpeper C + 10 percent Type I cement.

test. For lower levels of the ratio, the elastic rebound was both essentially linear and unique for both the untreated and stabilized soils studied. This agrees with Tate's (1) earlier findings. Figure 12, therefore, indicates that whereas the addition of portland cement to these soils reduced the elastic rebound caused by a given repeated load, the elastic rebound was no different for stabilized or untreated soils when repeated loads imposing similar ratios of $\Delta\sigma_r/\Delta\sigma_s$ were employed. This indicates that the magnitude of the elastic rebound under the action of repeated loads will not be reduced by the addition of portland cement if at the same time we attempt to take full advantage of increased strength and stiffness of the cement-treated soils.

If the relationship shown in Figure 12 is truly unique for any given soil, then a method for predicting the amount of elastic rebound produced by a given intensity of repeated load can be developed if the conventional stress-strain relationship for either the treated or untreated soil is known. Further studies of this relationship are needed, however.

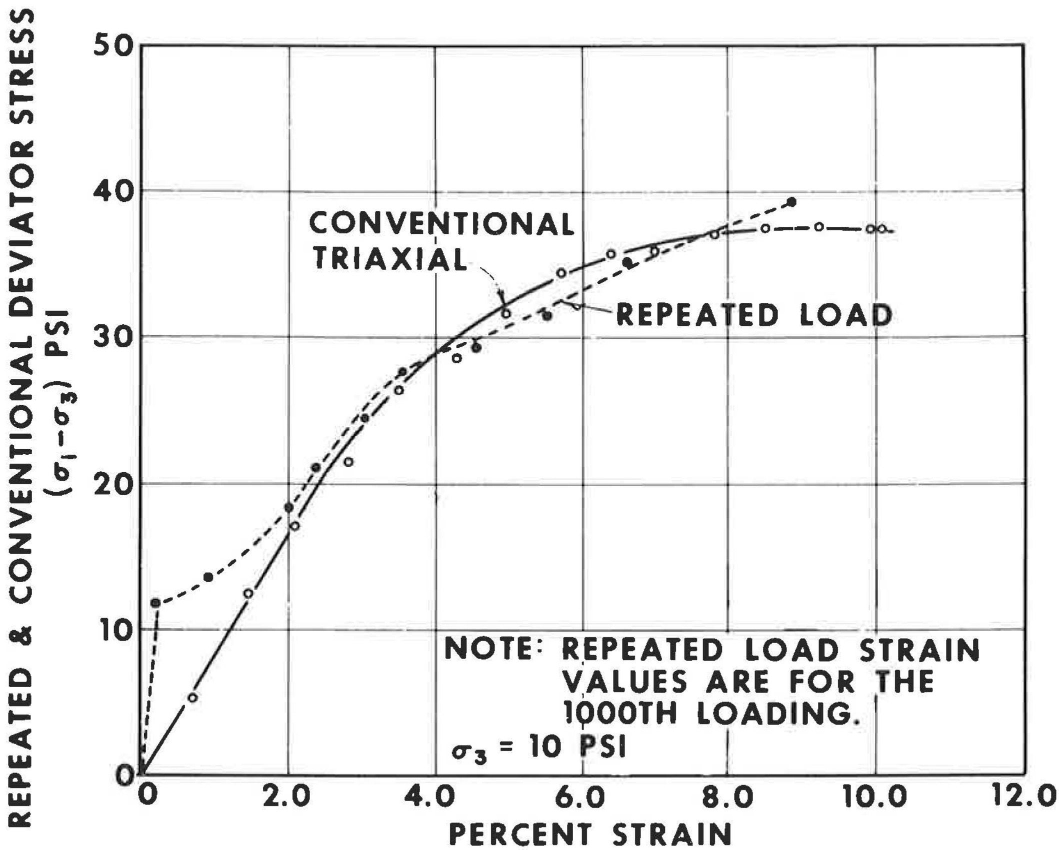

Figure 11. Repeated and conventional load stress vs strain curves for unstabilized Culpeper C soil.

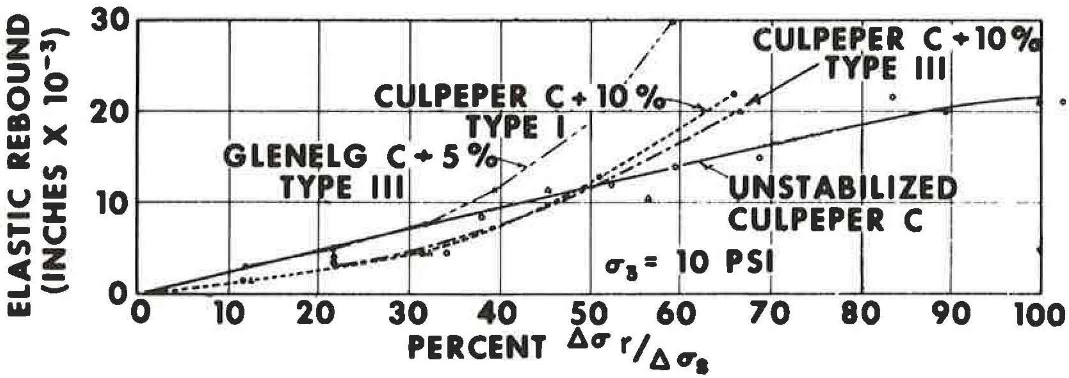

Figure 12. Elastic rebound vs percent ultimate gradually applied stress for soils indicated.

CONCLUSIONS

As a result of this study the following conclusions seem justified:

1. The ultimate strengths and stiffnesses of soils employed in this study were increased many times when they were stabilized with portland cement. This was verified by both conventional triaxial and repeated load testing.

2. For unstabilized Culpeper C soil there was no apparent difference between the conventional stress-strain curve and the repeated load stress-strain curve.

3. The ultimate strengths of both the soil-cement and cement-modified soils, as determined with repeated loads, was considerably less than the ultimate strength obtained for identical samples using conventional loading apparatus; however, the strain at failure remained nearly the same for both types of loading.

4. The stiffness of the soil-cement, as measured by a soil modulus, was little different when determined from either repeated load or conventional stress-strain curves. This was not true for the cement-modified soil (Glenelg C + 5 percent Type III cement) in that the stress-strain curve, as determined by the repeated load test, was less steep and, therefore, gave a lower secant modulus. This indicates that gradually applied load moduli may not be indicative of repeated load moduli in cement-stabilized soils. Further research concerning these findings should be undertaken.

5. The amount of elastic rebound increased linearly with increased ratio of $\Delta\sigma_r/\Delta\sigma_s$ up to values of $\Delta\sigma_r/\Delta\sigma_s = 0.3$ for all soils studied, whether treated or untreated. This appears to be a significant finding for if further research corroborates these results, a prediction of the amount of elastic rebound for a soil can be made from the results of only a conventional triaxial load test.

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