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The Effects of Time Dependent Stress-Path on The Plastic and Elastic Deformation of Sand and Clay Soils Subjected to Dynamic Loading

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SYNOPSIS Cylindrical cyclic loading tests were used to study the effects of time dependent stress-path on the plastic and elastic deformations of sand and clay soil samples. The test materials were obtained from the subgrade of existing highway pavements located throughout the state of Michigan. Approximately, 25 cylindrical soil samples (13.5 cm long, 5.5 cm in diameter) were tested under repeated loading conditions using different hydrostatic confining pressures and several time dependent stress-paths. In all tests, the first invariant of the stress tensor was cycled between two constant values and the first invariant of the stress deviator tensor was increased incrementally and cycled such that its minimum value was kept greater than 6.895 kPa. at all times.

Analysis of the test results indicated several findings, these include:

1) Increasing the first invariant of the stress deviator tensor with time,for sand samples, decreased the average rate and magnitude of the plastic deformation of the samples.
2) For clay samples, the rate and magnitude of the plastic and elastic deformations were found to be dependent on the first invariants of the stress tensor and stress deviator tensor, on the stress-path and on the sample parameters. For example, the elastic strains of two duplicate soil samples tested under the same stress conditions (same invariants of stress tensor and stress deviator tensor) were different by a factor of 2 to 100. The value of this factor was found to be a function of the time dependent stress path.

INTRODUCTION

The limitation of plastic deformation in a pavement section is a basic requirement in any structural design method of a pavement system. Consequently, the success of such design method depends upon the availability of reliable procedures for the determination of constitutive strength and stress-strain relationships for pavement and subgrade materials (1,2,3,4,5,6,7, 8,9 and 10). Further, researchers have indicated that for different sequence of applied stresses, total plastic deformation is greatly altered. For example, a soil sample or an embankment section subjected to (5x) stress intensity for 10 hours will experience more total plastic deformation than if it was subjected to (2.5x) stress intensity for 10 hours followed by (5x) stress intensity for another 10 hours.

This paper discusses the effects of stress-path on the plastic and elastic deformation of sand and clay materials subjected to cyclic loadings.

TEST MATERIALS

The primary materials used in this investigation were a clean unifrm sand and clay soils which are typical subgrade materials encountered throughout the lower peninsula of the state of Michigan. The grain size distribution curves are shown in Figures 1 and 2. The reconstituted sand samples were compacted using three different compaction methods (ASTM D698, ASTM D1557 and modified ASTM D698). The corresponding compaction efforts were 18,062 cm-kg/cm^3, 82,100 cm-kg/cm^3 and 7,224 cm-kg/cm^3 respectively. For more informations concerning compaction the reader should consult reference 11 in the bibliography. The clay samples on the other hand

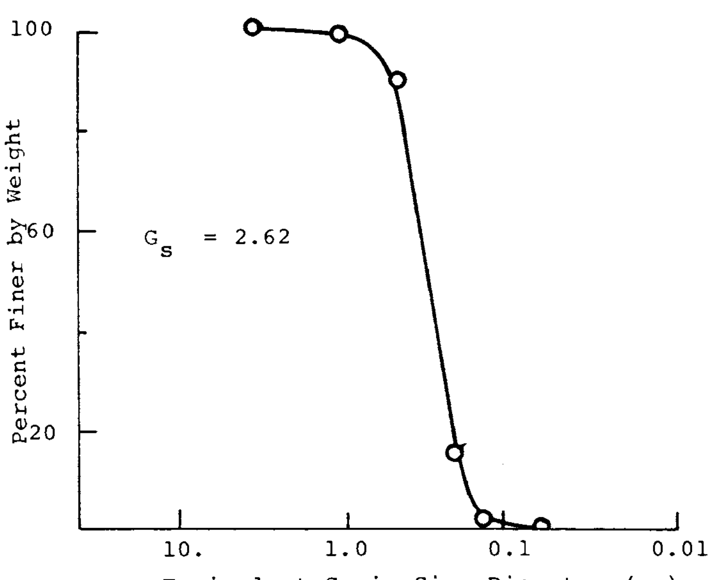

FIGURE 1 GRAIN SIZE DISTRIBUTION CURVE FOR HIGHWAY SUBGRADE SAND (11).

were relatively undisturbed tube samples.

TEST PROCEDURE

All test samples measured 5.4 cm in diameter and 13.6 cm in height. The sand samples were compacted and then subjected to 10,000 load repetitions under the specified confining pressure and cyclic loadings. The clay samples ,on the other hand, were trimmed, consolidated under the test confining pressure and then they were subjected to 30,000load applications under the specified cyclic stress. Also, several clay samples were tested under unconsolidated conditions. For both materials the axial resilient and plastic strains were measured. The radial strain and the pore water pressure were measured for the clay samples.

The loading system in this investigation consisted of a closed loop electro-hydraulic actuator interfaced with a minicomputer to control the loading mode and frequency.

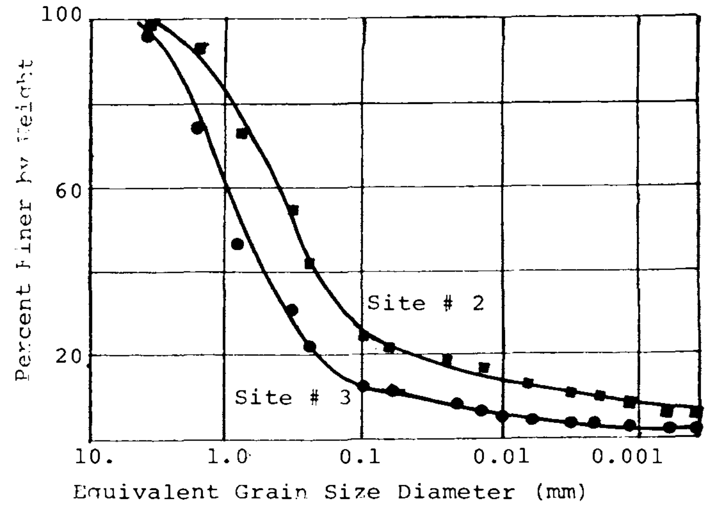

FIGURE 2 GRAIN SIZE DISTRIBUTION CURVE FOR HIGHWAY SUBGRADE CLAY.

TEST RESULTS AND DISCUSSION

Figure 3 shows plot of cumulative plastic strain (ε_p) versus the number of load applications (N) for two identical sand samples tested under different stress-path. Sample A3C was tested for ten thousand cycles at a principal stress difference of 103.42 kPa. Sample 3B was tested for ten thousand cycles at a principal stress difference of 68.95 kPa, the principal stress difference was then increased to 103.42 kPa and cycled for an additional ten thousand cycles. Examination of Figure 3 indicated that sample 3B experienced less permanent strain than did sample A3C. This was expected and agrees with results reported in the literature that cycling at low stress levels increases the resistance of sand to permanent strain under subsequent higher loads. cycling at low levels of principal stress difference causes permanent deformation due to rearrengement of particles. The stresses however, are not large enough to cause high permanent deformations but it forces the soil skeleton to assume more stable structure. When a moderately higher cyclic load is subsequently applied, the soil structure already possesses significantly higher resistance to deformation and more stability. Consequently, permanent strain due to the higher load will be small. If, however, the higher load had been applied to a virgin sample the stable structure would not have existed. In this case the rearrengement of soil particles would be more severe, resulting in larger permanent strain. It should be noted that the stable structure due to the stress-history may be destroyed if the second cyclic load is substantially higher than the first.

The effect of stress-history on the cumulative plastic strain could be thought of as analogous to the effect of particle interlocking due to higher densities and/or lower void ratio. A typical stress-strain curves showing the effect of particle interlocking is shown in Figure 4. The upper curve in the figure is characteristic of dense or very dense sand samples having a high degree of particle interlocking. The lower curve , on the other hand, is characteristic of loose sand. The strength of the dense sand reaches a peak value due to particle interlocking then drops to the same ultimate strength as that of the loose sand once the interlocking has been overcome. The interlocking caused by a low level cyclic loadings however, should not be attributed to sample densification, rather it is the results of structural arrangement between the soil particles.

Figure 5 shows plots of cumulative permanent and resilient strains versus the number of load applications for consolidated and unconsolidated clay samples. Examination of the figure indicated that the plastic strain of clay samples consolidated under the confining pressure and then subjected to undrained cyclic loadings is substantially lower than that of unconsolidated samples. Further, the value of the resilient strain ,at any load cycle, of the first sample is about half of that of the second sample. This difference,however, appeared to vanish as the number of load repetitions increased. It should be noted that similar results on different clay soils showed an increase in resilient strain of order of magnitude. Also, several clay samples were consolidated and tested in a fashion similar to that of the sand samples. The test results however, are still under investigations.

CONCLUSIONS

On the basis of this investigations the following conclusions are raeched:

1) The average rate and magnitude of the plastic (permanent)strain of sand and clay samples decreased as the time dependent stress-path is altered favorobly.
2) The resilient characteristics of clay samples depend upon the stress-history of the samples.

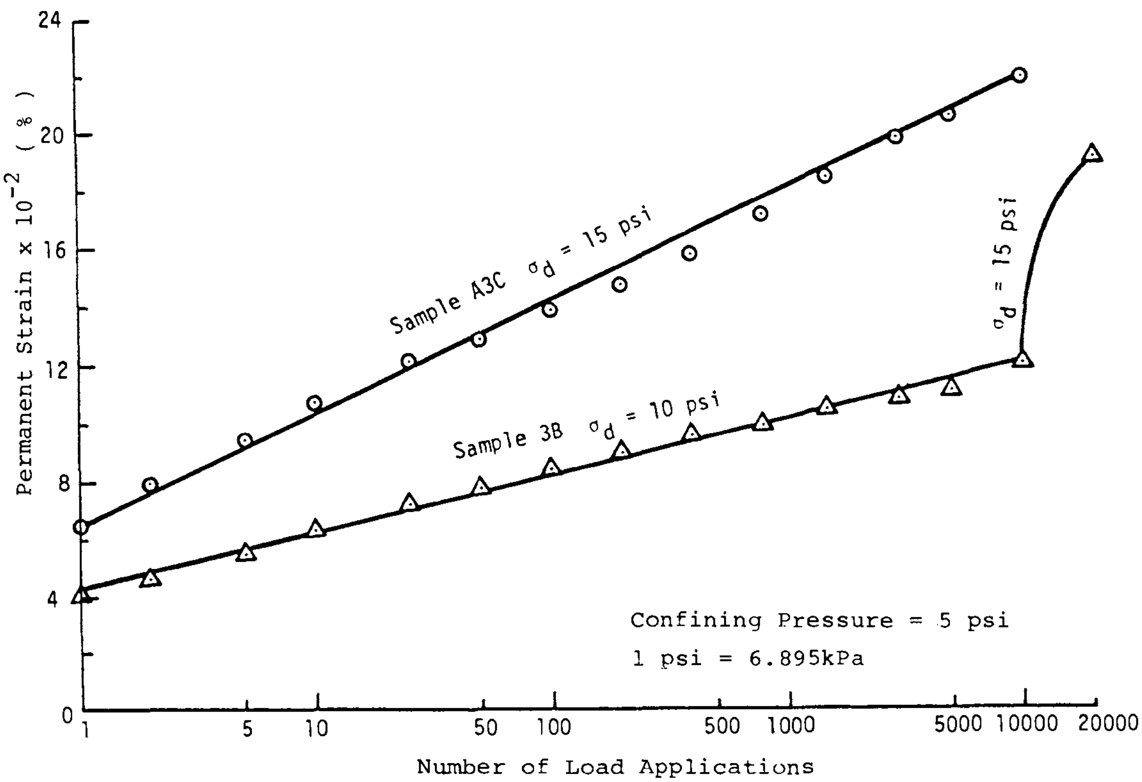

FIGURE 3 THE EFFECTS OF THE TIME DEPENDENT STRESS-PATH ON THE PERMANENT STRAIN OF SAND SAMPLES.

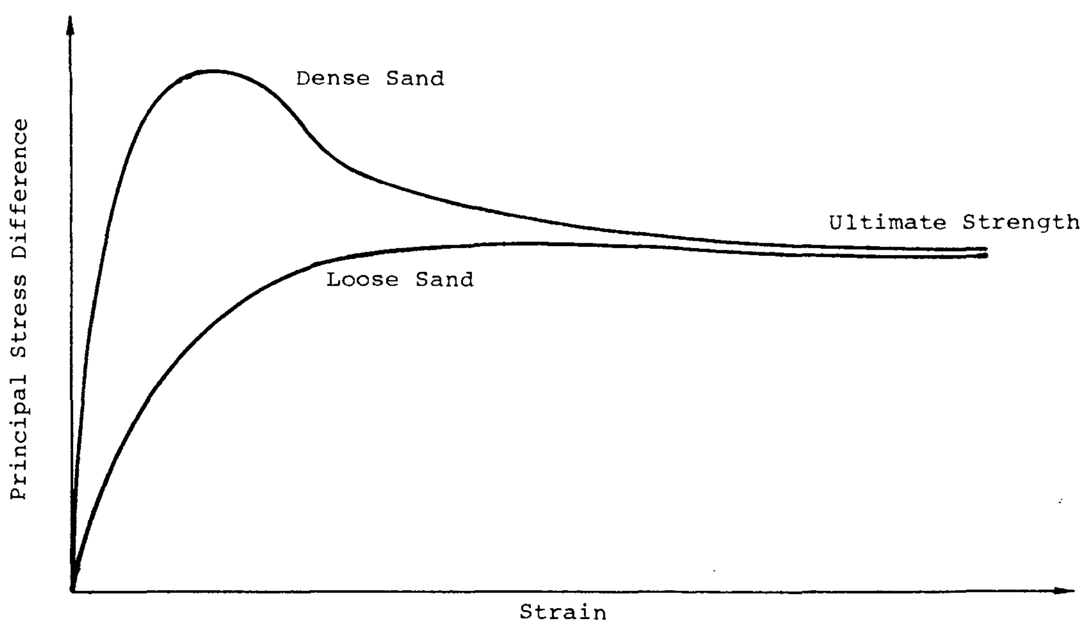

FIGURE 4 TYPICAL STRESS-STRAIN CURVES OF LOOSE AND DENSE SAND SHOWING THE EFFECTS OF PARTICLE INTERLOCKING DUE TO DENSITY.

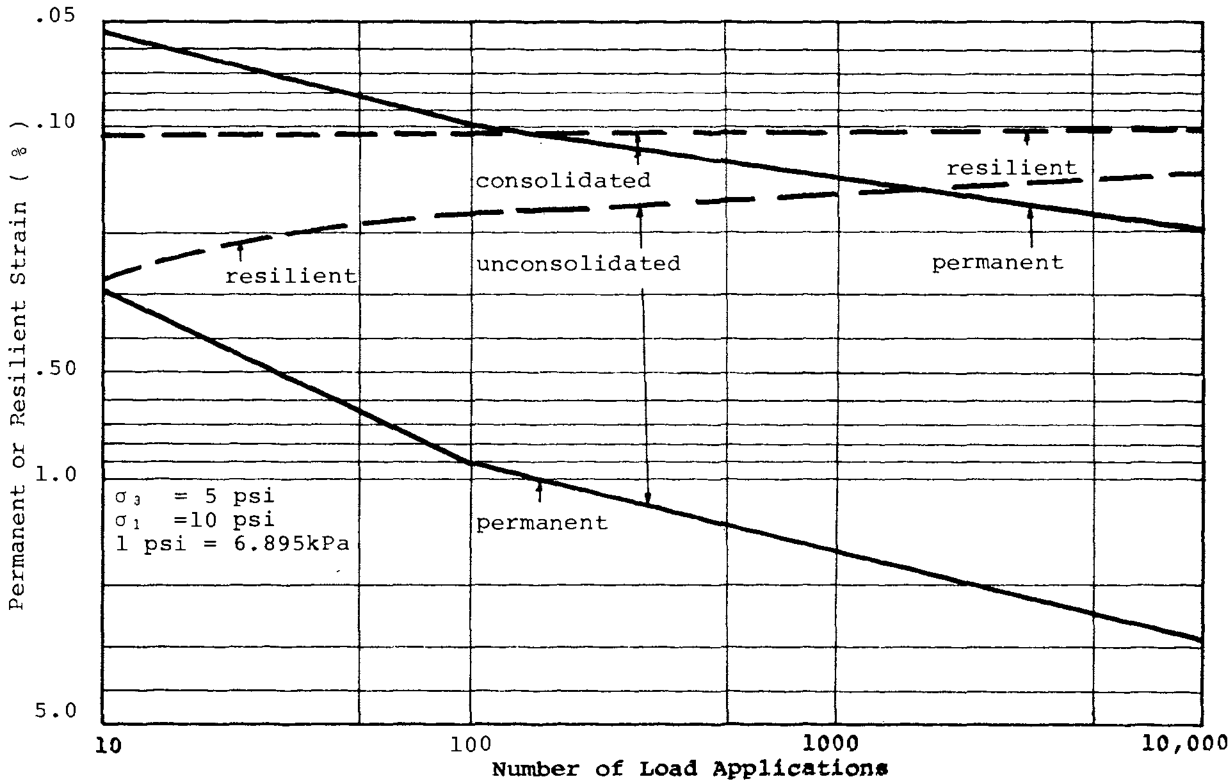

FIGURE 5 PERMANENT AND RESILIENT STRAINS VERSUS THE NUMBER OF LOAD APPLICATIONS FOR CLAY SOIL SAMPLES.

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