LABORATORY STUDY TO DETERMINE THE EFFECT OF SLIP-GENERATED SHEAR ON SOIL COMPACTION

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Preliminary findings from the field and from standard direct shear box tests indicate increased dry densities of soil due to normal pressure with added shear strains. The percent change attributed to shear in the direct shear testing device was much smaller than those obtained under tractor tires in field tests. To simulate the field condition better, a square, pure shear strain box was designed to fit the standard direct shear equipment. Tests were conducted on sand and sandy loam soils at moisture contents ranging from dry to saturation for normal pressures of 0.17, 0.32 and 0.63 kg/cm^2 with and without shear strains. The compaction produced was higher for each normal pressure with shear than without. Shear forces increased dry density changes between 20 and 50% for a constant normal pressure depending upon the moisture content in the range of 10 — 38%.

INTRODUCTION

Soil compaction is caused in agricultural soils mainly due to machinery operation. The degree of compaction is known to depend on several factors such as soil type, soil moisture content, contact pressure and wheel slip. Soane (1970) discussed soil properties and load characteristics likely to be involved in compaction under wheels, stressing the difficulties of measuring the components of an applied load. Davies et al. (1973) reported yield studies in which a maximum soil compaction was measured under tractors, working with different wheel loads and levels of wheel slip. Wheel slip was proved in some cases to be a more important cause of compaction than additional wheel loading, and this effect was more predominant for more powerful tractors. Only a few experimental studies have measured agricultural soil compaction as affected by shear strains (e.g. Chancellor 1971). Different soil types, especially those prone to severe compaction damage, need to be studied in order to verify the importance of wheel slip strains in soil density changes. Therefore, the objectives of this study were:

(a) To design a pure shear box to apply controlled normal pressures and shear strains to soil samples, and

(b) To determine the effects of normal loading together with shear strains on the compaction of certain soils at different moisture contents.

EXPERIMENTAL METHODS

Undisturbed sand and sandy loam field samples of dimensions 5.08 X 5.08 X 1.88 cm and different initial moisture contents were placed in a standard single-ring, square shear box. Loads of 4, 8, 16 and 32 kg were placed successively on each sample and a dial gauge was used to measure the changes in height of the soil volume. These tests were repeated for each series of samples with and without the application of a constant shear movement having a rate of approximately 1.5 mm/min. After each test the final sample dimensions were measured using a vernier caliper, and the sample weight and water content were taken. The results of these tests indicated increases in the density changes under normal pressure application which were due to the shear action in the soil. However, these changes were only of the order of 0.02 — 0.04 g/cc, whereas the same soils in the field had been observed to suffer density increases of more than 0.20 g/cc due to wheel slip being added to the action of wheel load on the soil (Raghavan et al. 1975). This discrepancy was most likely due to the relatively small volume of a soil sample which is sheared by the standard two-ring direct shear device (Fig. 1).

In order to compensate for this fact, a new shear box (Fig. 2) similar to Roscoe's (1953) was designed with a sample chamber of 10.16 X 10.16 X 2.54-cm dimensions, with two fixed vertical sides, and two moveable ends hinged at the bottom and connected to rotate together. This new device was constructed to simulate two dimensional shear patterns under the center of a slipping wheel (Fig. 3). The top plate in Fig. 2 sits on the sample and is used for normal loading. The two moveable ends can be used for pure shear deformation of the sample, one connected to the proving ring and the other connected to the dial gauge for measuring shear displacements. Compaction of the sample can be computed from the sample height readings of the dial gauge on the top plate.

As in the previous tests, undisturbed soil samples from the field were carefully trimmed to fit in the new shear box and their dimensions and weights measured. A load of 16 kg was applied on the test sample and the readings of the compression dial gauge were obtained at 6, 15 and 30 sec. The procedure was repeated for loads of 32 and 64 kg. At the end of 64 kg normal load, shear deformation was applied through the proving ring at constant rate of approximately 10%/min. Vertical and horizontal displacements of the top of the sample were taken

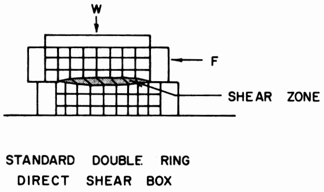

Figure 1. Shear patterns in a two-ring shear box.

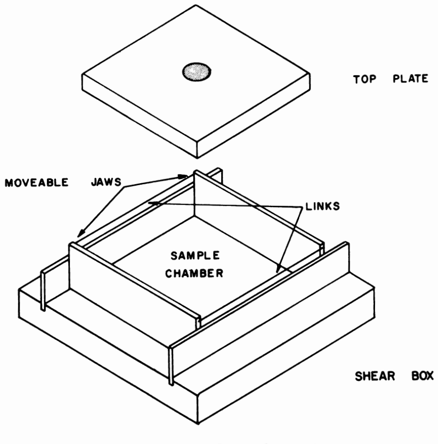

Figure 2. New shear box.

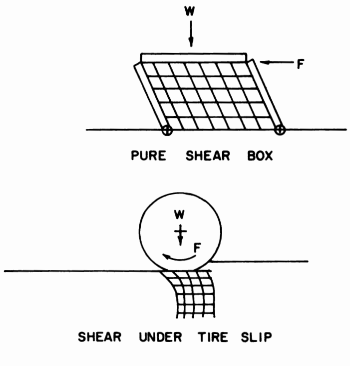

Figure 3. Comparison of pure shear box shear patterns with the field condition under slipping tires.

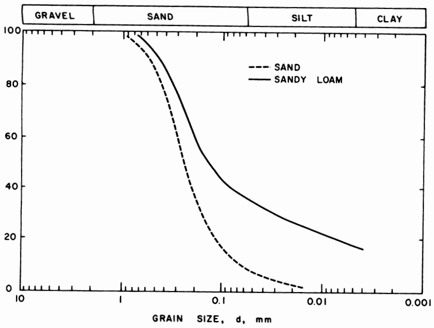

Figure 4. Grain size distribution of sand and sandy loam samples used for the tests.

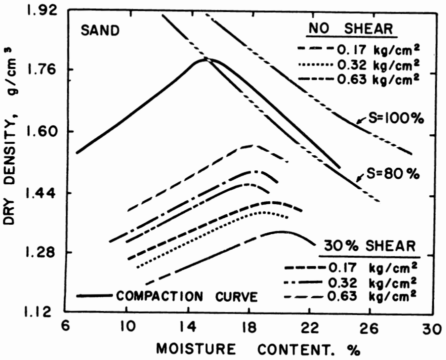

Figure 5. Dry density vs. moisture content for compaction and shear box tests on sandy soil.

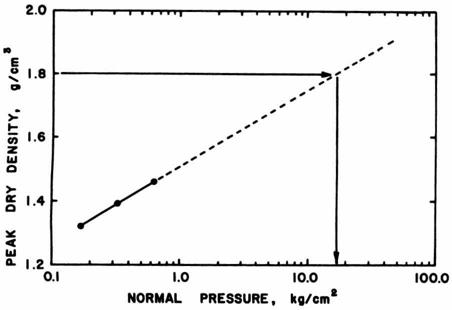

Figure 6. Peak density vs. normal pressure from compaction and shear box tests.

from the dial gauges at every 30 sec. This test was continued to a value of 35 — 40% shear strain, as indicated on the shear displacement gauge. At the end of the test, the vertical load was removed and the final reading of the compression dial gauge recorded. The final height of the sample was measured again at different positions and sample sections taken for moisture determination. The difference between initial and final readings of the sample height was compared to the compression dial gauge readings, and generally they both agreed to an accuracy of 0.01 cm. The test data were used to compute the dry density at each value of the normal load with and without shear forces. Test samples were prepared, and the above procedure was repeated for 16-, 32- and 64-kg loads followed by shear loading. The test series was repeated for moisture contents varying from dry to the maximum workable moisture content at increments of 4 — 5% by weight.

Particle size analyses were conducted on the soil samples following the method of Lambe (1951). The standard Proctor compaction test (Lambe 1951) was also performed on the samples to obtain an indication of the compaction resulting from a standard applied energy, using the average of three tests to represent each soil type.

RESULTS AND DISCUSSION

The grain size curves of the sand and sandy loam soils used in these tests are shown in Fig. 4. The conventional assessment of compaction behavior of the sand sample was obtained from the results of several standard Proctor compaction tests (Fig. 5). The peak density was obtained at 15.3%, the "optimum" moisture for this soil. On the same figure, curves of dry density vs. moisture content are drawn for each one of the normal pressures with and without shear from the results of the pure shear box. Dry densities were higher for increased normal pressures as was expected. However, the peaks for dry density occurred at different moisture contents depending upon the normal pressure. These values were 19.5, 18.3 and 17.2% for pressures of 0.17, 0.32 and 0.63 kg/cm^2, respectively. The apparent normal pressure developed in a Proctor compaction test is much higher than the ones used in the shear box experiments. The peak density for each normal pressure was plotted against the log of pressure, and a straight line relation was obtained. By extrapolating the line to the peak density of the Proctor compaction curve, a value of 17 kg/cm^2 is read (Fig. 6) for the apparent pressure applied by this conventional test.

To show the effect of shear strain on density changes, it was decided to present the densities after 30% shear strain had been applied to the samples. In the field this amount would correspond to a 9-cm horizontal deformation of the surface resulting in shear strains extending a depth of 30 cm into the soil. The lines of resultant density, when 30% shear strain was applied (Fig. 5), were observed to have considerably higher dry densities for a given moisture content than those for the tests without shear. Dry densities at 0.17 kg/cm^2 normal pressure with 30% shear strain are higher than that of 0.32 kg/cm^2 without shear. Similar results can be observed for the other pressure levels applied, which means that the application of 30% shear strain had a greater effect on dry density increases than that from doubling the normal pressure. Davies et al. (1973) mentioned similar results in their field trials.

The peak values of density for shear combined with normal pressure were at the same moisture content as those of normal pressure applied alone. A plot of change in dry density vs. moisture content was obtained from the data as seen in Fig. 7. For all the normal pressures considered, a maximum of 0.20 g/cm^3 in change in dry density was observed due to added shear strain effects. These figures are similar to the results of the field study (Raghavan et al. 1975) for sandy soil having the same particle size distribution.

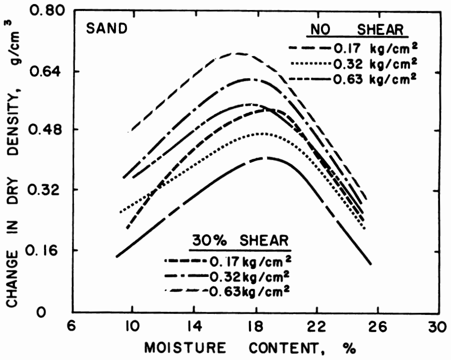

Figure 7. Change in dry density vs. moisture content for tests in a pure shear box with and without shear for sandy soil.

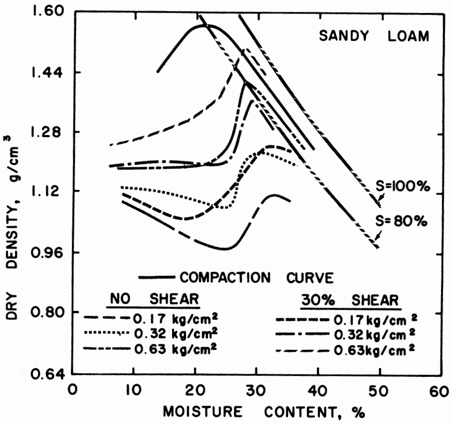

Figure 8. Dry density vs. moisture content for compaction and shear box tests on sandy loam soil.

Analyses were performed also on the results of tests conducted on sandy loam soil, whose particle distribution is shown in Fig. 4. Compaction results were obtained from the standard Proctor compaction tests, and the moisture content for the peak value of density was found to be 22% (Fig. 8). On the same figure, dry density vs. moisture content curves were obtained for three different normal pressures with and without 30% shear strain. The peak of dry density was observed at consistently higher moisture contents for decreases in applied normal pressure levels. At 0.17 kg/cm^2, dry density decreased up to a moisture content of 25%, and then increased, reaching a maximum at 33%. Such an initial decrease was observed for all the three normal pressures, the effect, however, being less at higher normal pressures. No reduction in dry density was obtained for the Proctor compaction curve, whose equivalent pressure is much higher than the three pressures applied in the shear box. Again, shear strain had an effect in