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GYRATORY TESTING OF SUBGRADE SOILS

LES ESSAIS GYRATORIQUES DES SOUS-SOLS DES CHAUSSEES
ГИРОСКОПИЧЕСКИЕ ИСПЫТАНИЯ ГРУНТОВ

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SYNOPSIS. The paper describes the use of a gyratory testing machine for evaluating the properties of subgrade soils. In this apparatus, a soil sample is subjected to a normal pressure and a cyclic shearing stress. The cyclic shear strain, and hence soil stiffness, is monitored continuously during the test. Also, volumetric strain is measured. The paper summarizes results of gyratory tests of 320 samples of a red silty clay (CL) and 180 samples of a tan silty sand (SM). The stiffness and compressibility are shown to be more significantly affected by shear stress than by normal stress. The soil stiffness, as measured by gyratory testing, correlates with results of penetration tests. The compressibility from the gyratory test does not correlate well with the results of consolidation tests.

INTRODUCTION

Gyratory testing is a method for evaluating the response of soils to cyclic loads. The concept of gyratory testing originated in the Texas Highway Department (Ortolani and Sandberg 1952) and was further developed by the U. S. Army Corps of Engineers (Waterways Experiment Station 1962a). Early research with this apparatus was directed primarily toward applications to bituminous materials and secondly to compaction of soils (Waterways Experiment Station 1962b, Abbott 1968, Fenwick 1969). Only limited studies have been reported on the use of the gyratory machine for testing the quality of compacted soils (Waterways Experiment Station 1962c, McRae 1967, Miller 1967). This paper reports a study of gyratory testing to evaluate the properties of soils subjected to cyclic loading.

GYRATORY APPARATUS

A schematic diagram of the gyratory test mechanism is shown in Fig. 1. The soil sample is placed in a 4 in. (10 cm) diameter mold (A), which then is inserted in the gyratory chuck (B). A vertical normal pressure, P, is applied with the lower hydraulic ram (F). Air pressure is applied to the upper roller mechanism (D). This roller pressure, R, applies shearing stress to the sample, which causes distortion or shearing strain. Rotation of the roller mechanism (K) at the rate of 25 revolutions per minute produces gyratory motion and cyclic reversals of shear stress and strain. The cyclic variation of the shear strain, which is herein referred to as the gyratory shear angle, is recorded on the gyrograph (I). The gyrograph provides a con-

tinuous record of the shear strain for a relatively constant shear stress and confining pressure, and thus reflects any change in sample stiffness during the test. Changes in sample thickness, and hence density or volumetric strain, are monitored throughout the test with a dial gage attached to the lower ram (F).

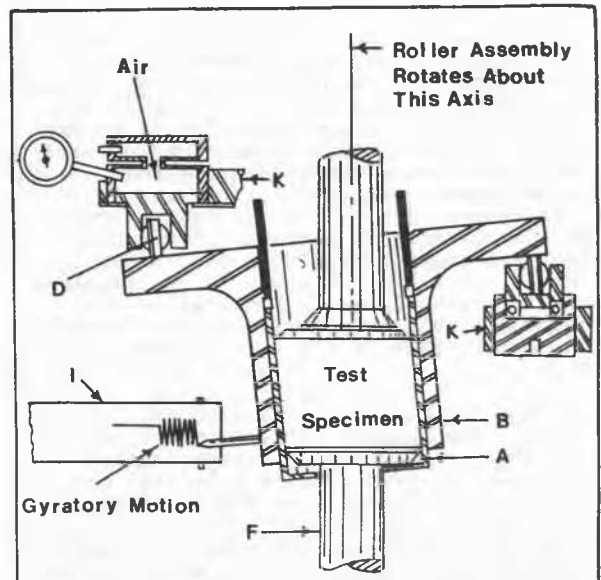


FIG. 1. Schematic diagram of gyratory machine.

TEST PROGRAM

The test program was devised (a) to investigate the effects of the gyratory shear and normal stress levels on the soil responses and (b) to evaluate the relation of the gyratory responses to the results of more conventional soil tests. The effects of the initial moisture-density conditions of the samples also were considered.

The effects of the normal and shear stress levels were studied in terms of the gyratory ram and roller pressures, respectively. The ram pressure, P , is the vertical normal stress applied to the sample. The roller pressure, R , determines the magnitude of the applied shearing stress but is not numerically equal to it. However, for convenience, the test results are presented in terms of the directly measured roller pressure rather than the computed shear stress.

Compacted samples of two soils were used in the test program. The first was a red silty clay (CL) with $LL = 39\%$ and $PI = 15\%$. The second was a non-plastic tan silty sand (SM). Conventional impact compaction methods were used to prepare samples at 20 different initial moisture-density conditions. Five moisture contents and four compactive efforts were used. For the silty clay, 320 samples were prepared and tested, 16 at each initial moisture-density condition. Each sample was tested under a different combination of four ram and four roller pressures, thus permitting the study of gyratory normal and shear stress effects at each initial condition. For the silty sand, nine combinations of three ram and three roller pressures were used at each initial condition, and thus only 180 samples were tested.

Each sample was subjected to 500 cycles of the gyratory stresses. This duration was sufficient for samples either to become completely unstable or to reach a stable equilibrium condition. The soil stiffness at the end of the test was measured in terms of the gyratory shear angle produced under the applied stresses. For small angles, the gyratory shear angle in 10^{-2} radians is equal to the shear strain in percent. After completion of each gyratory test, a CBR-type penetration test was performed on the sample. The bearing ratio from the penetration test was defined as the stress required to obtain 0.1 in. penetration of a 1 in. diameter piston.

Twelve consolidation tests were conducted on each soil. Two samples were compacted to each of the six different moisture-density conditions. One sample at each initial condition was consolidated from the as-compacted moisture content and the other was soaked prior to consolidation. The compressibility characteristics of these samples were compared with the final volumetric strains for the gyratory tests.

RESULTS

Soil Stiffness - Fig. 2 illustrates the stiffness of the silty clay, as measured by the gyratory shear angle and the CBR-like penetration test. Each data point represents the average of sixteen tests at the same initial moisture-density condition. Curves have been constructed through points of equal compactive effort with E-1 representing the lowest effort and E-4 the highest effort. Compactive efforts E-2 and E-4 correspond to the energy inputs used in Standard and Modified Proctor Tests, respectively.

The bearing ratio curves show moisture-density effects typical of compacted cohesive soils, i.e., on the dry side of optimum, the strength is greatly affected by compactive effort or density, while on the wet side the strength depends primarily on the moisture content. Similar results are observed from the gyratory tests. However, the curves are inverted because a low gyratory shear angle is indicative of high stiffness or strength. Thus, in Fig. 3 a linear correlation was obtained between the inverse of the gyratory shear angle and the bearing ratio for each initial moisture-density condition. Similar data also were plotted in Fig. 3 for the silty sand, and again a linear correlation was obtained. However, a different line was obtained for each soil because different combinations of gyratory shear and normal

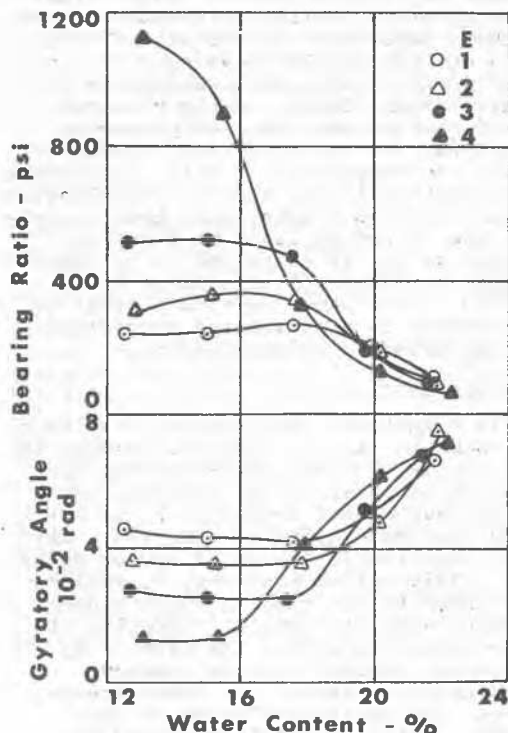


FIG. 2. Final gyratory shear angle and bearing vs. water content, silty clay.

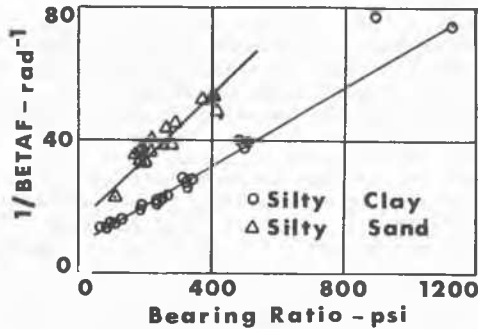


FIG. 3. Inverse of final gyrotory shear angle vs. bearing ratio.

stresses were used for each soil. If common normal and shear stresses had been used for both soils, a single correlation curve should have been obtained.

Volumetric Strain - Volumetric strains for the gyrotory tests are plotted as a function of the initial moisture-density conditions for the silty clay in Fig. 4 and for the silty sand in Fig. 5. Each data point in Fig. 4 represents the average volumetric strain for sixteen tests and each point in Fig. 5 represents the average of nine tests. For both soils, the volumetric strain decreased with increasing initial density. For very dense samples of the silty clay at low moisture contents, the gyrotory tests actually produced expansion, or loss of density. However, the influence of moisture content on volumetric strain was quite different for the two soils. This can be explained on the basis of the difference in permeability of the two soils. Because the gyrotory test is a short term test, it will behave as either a drained or an undrained test depending on the permeability of the test specimen. If, as in the case of the silty clay, the sample is undrained, volumetric strain is produced by reducing air voids. When saturation is approached, the sample is remolded at essentially constant volume. Consequently, samples prepared wet of optimum at high initial degrees of saturation undergo relatively little volume change. However, if, as in the case of the silty sand, the soil is pervious enough to permit at least partial drainage, the volumetric strain is not limited as saturation is approached and high volumetric strains can be obtained at high initial moisture contents. Water was observed draining from the silty sand samples at high initial moisture contents.

The volumetric strains produced in gyrotory tests did not correlate with those produced in consolidation tests. Two reasons may be given to explain this observation. First, the consolidation test always is a drained test in which volumetric strains are produced by expulsion of water, whereas the gyrotory will behave as a drained, undrained, or partially drained test, depending on the

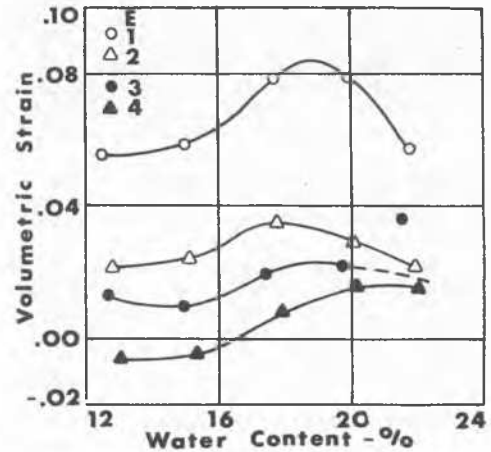


FIG. 4. Volumetric strain vs. water content, silty clay.

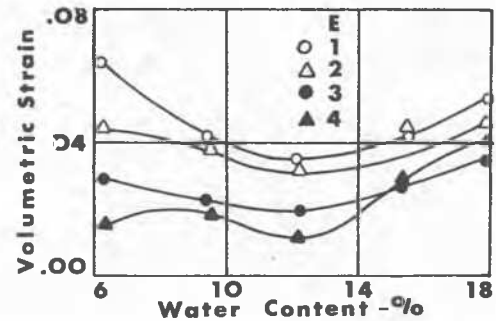


FIG. 5. Volumetric strain vs. water content, silty sand.

permeability of the sample. In cases of essentially undrained behavior, the volumetric strains are limited to that produced by compression and/or expulsion of air. Secondly the shear stresses present in the gyrotory test can produce significant expansion or compression. Thus, depending upon the specific test conditions, the net volumetric strain in the gyrotory test may be greater or less than that produced by a comparable normal pressure in a consolidation test.

Because the volumetric responses in gyrotory and consolidation testing generally are not the same, it is worth considering the relative significance of these tests. It seems clear that the consolidation tests is more relevant to the design of embankments, for which the major design load is the long term dead load of the embankment itself. However, for highway or airfield subgrades, the major design consideration becomes the repetitive wheel loads rather than the dead load of the pavement. In this case, the appropriateness

of the consolidation test for prediction of the volumetric response to traffic loads can be seriously questioned. A gyratory test, in which the stress levels have been adjusted to simulate the stresses produced in the prototype subgrade by traffic loads, would seem to produce much more meaningful results.

Effects of Ram and Roller Pressures - The effects of the gyratory ram and roller pressures are presented for the silty clay in Fig. 6 and 8a and for the silty sand in Fig. 7 and 8b. These effects were separated from moisture-density effects by averaging the results of all tests in which a common ram and roller pressure were used. Thus, each data point plotted in these figures represents the average response of 20 tests, each conducted on a sample at a different initial moisture-density condition.

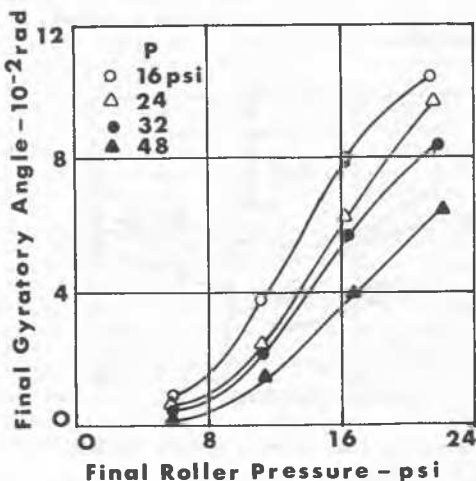


FIG. 6. Final gyratory shear angle vs. roller pressure, silty clay.

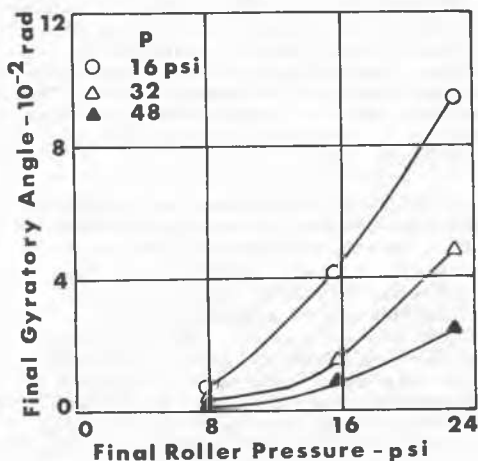


FIG. 7. Final gyratory shear angle vs. roller pressure, silty sand.

Essentially similar results were obtained for both soils. In Fig. 6 and 7, the gyratory shear angle is seen to increase with increasing roller pressure and to decrease with increasing confining pressure. The variation of gyratory angle with roller pressure is non-linear at low roller pressures but becomes approximately linear at higher roller pressures. The nonlinearity at low roller pressures is attributable to side friction effects, i.e., a certain minimum roller pressure is required to overcome the side friction of the mold. This minimum roller pressure appears to increase with increasing confining pressure because the side friction increases with increasing confining pressure. In Fig. 6, the reversal of curvature of the uppermost curve at the highest roller pressure is due to the physical limitations of the gyratory test machine. At these extreme testing conditions, the air roller piston became fully extended and larger strains could not be produced.

For both soils, the gyratory shear angle seems to be more significantly affected by roller pressure than by confining pressure. However, the confining pressure had a greater effect on silty sand than on the silty clay. This is reasonable because the silty sand tended to behave more like a cohesionless granular soil, in which the stiffness is strongly related to the confining pressure.

The influence of the ram and roller pressure on volumetric strain is illustrated in Fig. 8. The volumetric strain increased with both increasing roller pressure and increasing confining pressure. For both soils, this strain component was almost linearly related

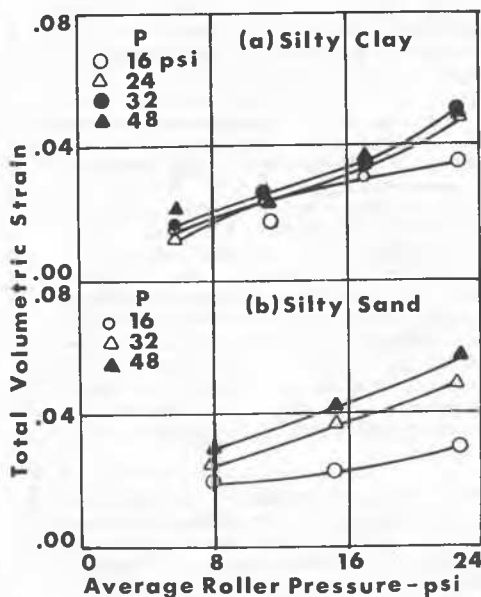


FIG. 8. Volumetric strain vs. roller pressure.

to roller pressure, and the roller pressure effect was much greater than the confining pressure effect. As was true for the stiffness, the effect of confining pressure was more significant for the silty sand than for the silty clay.

In summary, the data presented in Fig. 6-8 indicate that in general both the volumetric strain and the stiffness are more significantly influenced by roller pressure than by the confining pressure. Hence, the selection of an appropriate roller pressure, or shear stress level, becomes more critical than the selection of the ram pressure. Moreover, at a given confining pressure level, both responses tend to increase linearly with increasing roller pressure or shear stress level. However, in the case of stiffness, this linear response is observed only when the roller pressure is sufficiently large to overcome side friction effects.

APPLICATIONS

Gyratory testing appears to have potential application to the evaluation of soil behavior under cyclic loads. Potential problem areas include highway and airfield pavement subgrades and soils beneath machine foundations. The gyratory ram and roller pressures are adjusted to simulate the normal and shear stresses anticipated in the prototype condition.

Either compacted or natural soils can be tested. Environmental effects, such as moisture changes or freezing, can be studied.

Test results can be used to determine compaction levels required to obtain satisfactory performance for specified loading and environmental conditions. Also, the effects of increased loads on existing installations can be evaluated. For example, an undisturbed sample of an existing pavement subgrade can be tested to determine the effect of a heavy aircraft or truck wheel load which exceeds the original design loads for the pavement.

CONCLUSIONS

1. The stiffness and compressibility of soils subjected to cyclic loadings can be evaluated from gyratory tests. The influence of initial moisture-density conditions can be easily observed.
2. The stiffness as measured by the gyratory shear angle correlates well with a bearing ratio from a CBR-type penetration test. Similar correlations can be anticipated with other conventional shear tests.
3. The volumetric strains produced by gyratory testing do not correlate with those produced in consolidation tests. Differences are attributed to the shearing effects and variable drainage conditions

present in gyratory tests. The results of gyratory tests appear more valid than conventional consolidation tests for repeated load applications, such as pavement subgrades.

4. The ram, or confining, pressure had a smaller effect on soil response than did the roller pressure, which produces the shearing stresses.
5. At low roller pressures, side friction between the sample and the mold has a significant effect on soil response, particularly the stiffness.

ACKNOWLEDGEMENTS

The research reported herein was conducted at North Carolina State University as a part of the Highway Research Program under the joint sponsorship of the North Carolina State Highway Commission and the Federal Highway Administration. The gyratory testing machine was provided by the U. S. Army Waterways Experiment Station.

REFERENCES

- ABBOTT, W. B. (1968), "Gyratory compaction of soil: Pit-run gravel, data report," Report 1, Technical Report S-68-5, Waterways Experiment Station, Vicksburg, Mississippi.
- FENWICK, W. B. (1969), "Gyratory compaction of soil: Crushed limestone, data report," Report 3, Technical Report S-68-6, Waterways Experiment Station, Vicksburg, Mississippi.
- McRAE, J. L. (1967), "Design of subsurface and surface against detrimental compaction and shear in the finished structure," Proceedings, 2nd International Conference on the Structural Design of Asphalt Pavements, University of Michigan, Ann Arbor, Michigan pp. 59-69.
- MILLER, W. W. (1967), "Correlation of gyratory testing variables with defined strength characteristics of two soil types compacted at two energy inputs," M. S. Thesis, North Carolina State University, Raleigh, North Carolina.
- ORTOLANI, L. and SANDBERG, H. A., Jr. (1952), "The gyratory test method of molding asphaltic concrete test specimens; its development and correlation with field compaction methods," Proceedings, Association of Asphalt Paving Technologists, 21: 280-297.
- WATERWAYS EXPERIMENT STATION (1962a), "Development of the gyratory testing machine and procedures for testing bituminous paving mixtures," Technical Report No. 3-595, Vicksburg, Mississippi.

WATERWAYS EXPERIMENT STATION (1962b), "Gyratory compaction method for determining density requirements for subgrade and base of flexible pavements," Misc. Paper No. 4-494, Vicksburg, Mississippi.

WATERWAYS EXPERIMENT STATION (1962c), "Feasibility study of the gyratory machine for testing soils," Misc. Paper No. 3-474, Vicksburg, Mississippi.