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Small Scale Load Tests on a Soil-Geotextile-Aggregate System

Une eprevus de fardeau de petite magnitude sur une systéme des agrégats de sol géotextile

Small scale laboratory tests were performed to study the effect of a geotextile on a soil-geotextile-aggregate system. The analysis technique lead to qualitative conclusions regarding performance parameters that may be used (with due caution) in developing quantitative data for field applications. The tests demonstrate that a geotextile disc slightly larger than the loading plate has a very significant reinforcing effect on the system; whereas, a disc identical in size to the loading plate does not appear to have any effect. The tests also indicate that the effect of a limited expanse of geotextile diminishes as the thickness of the aggregate increases.

Les expériences de laboratoire, simple, était preformés pour étudier l'effet du geotextile d'une systéme agrégat de sol-geotextile. Les analyses ont produit les conclusions qualitatif au subjet des representations de parameter qu'ils ont utilizés pour obtenir les informations qualitatif. Pour les applications due champ des experiments ont demontrés que la disque geotextile, qui est un peu grandeur que l'assiett chargement, a un effet renforcement de signification au systéme. Tandis qu'une disque avec une taille identique que l'assiette chargement n'apparaîte pas avoir un effet. Les expériences indiquent, aussi, que l'effet du expanse limité de geotextile diminue puisque l'épaisse des agrégats ont augmentés.

1. INTRODUCTION

Several theoretical and experimental studies indicate that the inclusion of a geotextile changes the stresses within soil-geotextile-aggregate systems, thus improving their performance. Several researchers have presented theoretical approaches to calculating the supporting effect of the geotextile. These approaches consider only the vertical component of the tensile stresses in the geotextile as it is stretched over the curved surface caused by rutting. Kinney (1979) extended these concepts to include the energy absorption characteristics of the geotextile and the effects of the shear stresses developed on the subgrade by the geotextile. All of these studies indicate that for the beneficial effects to be substantial the tensile stresses in the geotextile must be significant and the profile must have undergone deformation under the load.

Field and laboratory evidence shows that the presence of the geotextile may have a stabilizing effect on the system, even at small deformations before any significant tension could possibly develop in the geotextile. There is also indirect but supportive evidence; for example, geotextiles are being used more frequently in railroad applications where the geotextile strains should remain very low. A number of publications point out that the geotextile changes the stresses within the railroad roadbed; however, the available data is inconclusive.

The mechanics by which the geotextile could change the stress distributions within a system prior to developing signficant tension in the geotextile has not been adequately explained. The stress-strain characteristics of both subgrade and aggregate are stress dependent. Minor changes in horizontal stress distributions therefore cause changes in the stress-strain characteristics, which in turn cause changes in the stress distributions and so on. Hence, fairly minor externally caused changes in the horizontal stress distribution can have a significant effect on the system performance. The stress-strain characteristics of granular materials are particularly susceptible to changes in stress when the minor principal stress is near zero. During loading the tendency is for the bottom of the aggregate to go into tensile strain in the horizontal direction and the stress in that direction to drop to near zero. If the geotextile were to restrain the bottom of the aggregate in the horizontal direction even slightly, it could cause significant changes in the entire system performance.

The purpose of the tests was to study the effects of a geotextile on a soil-geotextile-aggregate system in which no tension was developed in the geotextile outside of the area of direct influence of the load.

A small scale test apparatus consisting of a container, a cyclic dynamic loading system and a measuring system was designed for the study. A matrix of tests were performed. In each test a soft clay was placed in the bottom and up to 50mm of aggregate was placed on top. Some of the tests were performed with a geotextile placed between the two.

2. TEST APPARATUS AND MATERIALS

The small scale load tests consisted of placing clay, a geotextile and an aggregate in a cylindrical mold and loading the surface with a circular plate. The mold was 152mm in diameter and 106mm deep.

Several sizes of porous stones were used for loading plates. They ranged in size between 25mm and 80mm in diameter. The load was applied sinusoidally by a pneumatic piston with a 1.0 second period. The load ranged from a low value of 6.7 Newtons to a high value varying up to 32.7 Newtons. The apparatus is shown on Figure 1.

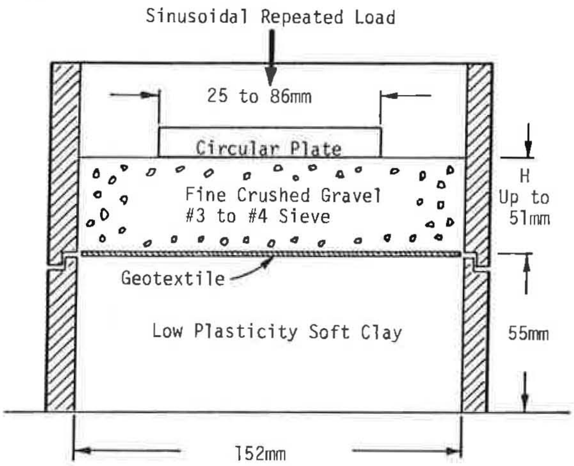

Fig. 1 Test Apparatus

The load was controlled by air pressure and recorded using a load cell. The permanent displacement of the loading piston was measured with a dial gauge.

A naturally occurring silty clay with a liquid limit of 36 and a plasticity index of 14 was used throughout all testing. The clay was mixed at slightly below the liquid limit and smeared into the mold. Water content and vane shear tests were made after every test.

The aggregate was a uniform crushed stone with all material passing the #3 sieve and retained on the #4 sieve. The aggregate was placed in the cell and compacted lightly by hand using a wooden rod. The aggregate ranged in thickness up to 50mm.

A 227gm per square meter heat-bonded, nonwoven polypropolene fabric was used throughout with the heat-bonded side down.

3. TEST RESULTS

Fifteen test series with a total of 61 tests were performed with varying conditions of geotextile placement, loading plate diameter, maximum cyclic load and aggregate thickness. The conclusions drawn are based on the results of all the tests, but only that data required to demonstrate particular points are shown herein.

3.1 Self Stabilizing Effect of Soil-Aggregate-Systems

Without exception the displacement per load cycle decreased with increasing number of load cycles. This is as expected and conforms with other experience to date. Although this response has been frequently observed, it is not well understood. A detailed discussion of the response is beyond the scope of this report; however, mention of its significance to geotextile reinforcement is relevant.

In systems which exhibit the self-stabilizing effect, any factors which retard rut development tend to accelerate the self-stabilizing effect. It should be noted that not all systems demonstrate this effect. Systems with highly sensitive soils or systems which exhibit pumping or liquefaction become softer with increasing number of load cycles.

3.2 General Effect of the Geotextile on the System Performance

The general effect of the geotextile on the test results can be seen by making three basic comparisons. Comparisons between systems with and without a geotextile and no aggregate (Figure 2, tests e and c) show that the geotextile increases the stability of the system slightly even when there is no aggregate present. This is probably due primarily to several factors which are significant to the test but which may not be significant in the field, such as the relative thickness of the geotextile and its ability to carry some bending moment. Both these properties tend to cause the load to be spread out on the clay, reducing displacement. In addition, the geotextile probably adheres to the clay more than the porous stone, thereby reducing lateral spreading of the clay and reducing displacement. These effects must be considered throughout the analysis of the test data.

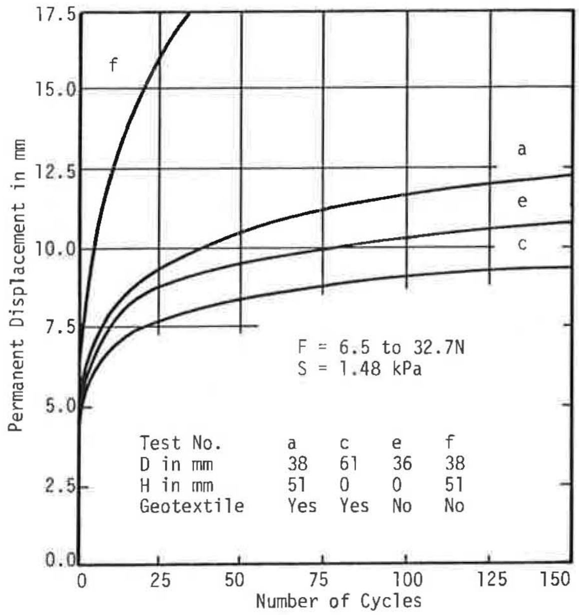

Fig. 2 Test Series No. 10

Comparisons between systems with and without a geotextile and 25mm of aggregate (Figure 2, Tests a and f) show that with 25mm of aggregate the geotextile has a very substantial stabilization effect. The accuracy of the data at low deformations was not adequate to determine at what point the stabilization effect became significant; however, it appears to have been at a displacement of about 5mm. This is a displacement to loading plate diameter ratio of about 0.13 which translates to a rut depth on the order of 25 to 100mm in typical field installations.

Comparisons between systems with and without a geotextile and 50mm of aggregate (Figure 3, Tests c and d) show that when 50mm of aggregate are present the geotextile has very little influence on the system response. Conceptually it seems reasonable that a geotextile will have a minimal effect on the system response if placed under a large thickness of aggregate. There are serious questions about the data from these tests at large thicknesses of aggregate because of the boundary conditions, hence care should be exercised in making this comparison.

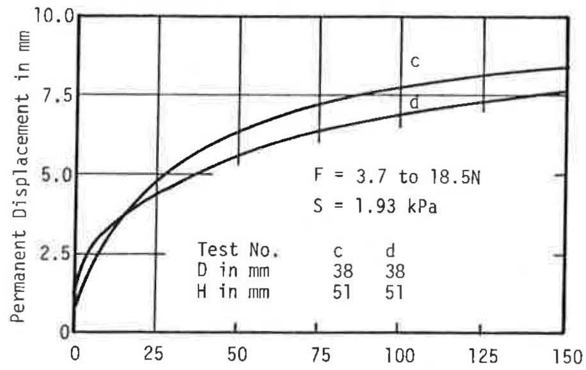

Fig. 3 Test Series No. 12

3.3 Effect of the Lateral Extent of the Geotextile in the Tests

Five tests were performed, as shown on Figure 4, to help evaluate the effect of the lateral extent of the geotextile under the loaded area. All aspects of the tests were held constant except for the lateral extent of the geotextile at the interface.

No geotextile was used in Test e. Tests d and c contained geotextile discs 38mm and 89mm in diameter respectively. Tests b and a both contained a 152mm diameter disc of geotextile, but in Test b the geotextile was cut at a diameter of 89mm around the center. An aggregate thickness of 25mm and a plate diameter of 38mm were used throughout.

Three significant conclusions are apparent from comparing these test results. The first comes from comparing tests without the geotextile and with the 38mm diameter disc of geotextile (Tests c and d, respectively). The two test's results are almost identical, indicating that the relatively small disc of geotextile did not change the system response significantly. This leads to the conclusion that the geotextile must have some minimum extent to be of any benefit. This conclusion is not axiomatic. The center of the profile has the highest normal stresses, the largest radial tensile strains and the most potential for intermixing of aggregate and clay. It would therefore seem reasonable to assume that even a small area of geotextile under the center of the load would improve the performance, but it did not in the tests.

The second conclusion is apparent from comparing tests with 89mm and 152mm discs of geotextile (Tests c and a, respectively). It appears from these tests that the larger disc of geotextile is slightly more beneficial than the smaller. There are several obvious explanations for this effect:

* The load distribution may spread out through the granular material slightly past the extent of the 89mm disc of geotextile.
* There may be significant tensile stresses developed in the geotextile from outside the direct influence of the loading plate, resulting in a drum effect.
* The bending stiffness of the geotextile may effect the small scale test results.

The third conclusion is apparent from comparing the results of Tests c, b and a. The load displacement history for Test b with the cut 152mm diameter disc lies between Test c with the 89mm diameter and Test a with the 152mm diameter disc. It appears from these tests that cutting the geotextile decreases its effectiveness, and the geotextile outside the cut is still somewhat effective. Therefore, the radial tension in the geotextile at this radius in these tests must be important. The origin of the tensile stresses is not apparent. It could be due to direct load induced, outward directed shear stresses from the aggregate, or due to outward directed shear stress on the geotextile from the clay outside the loaded area as the geotextile is stretched over the longer rutted surface.

3.4 Effect of Geotextile on Load Distribution

The first two sections have discussed qualitatively the effects of a geotextile on the test results. This section is devoted to a quantitative analysis of the data and a discussion of how this might be interpreted in terms of field response. The method of analysis used on the test data is unique and would be applicable to many types of future testing.

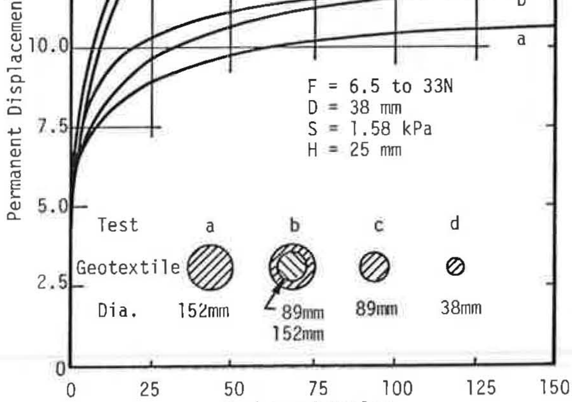

Fig. 4 Test Series No. 3

3.4.1 Method of Analysis

Basically the method of analysis is simple. Loads of various magnitudes were applied to various sizes of loading plates placed directly on the clay. The responses of these tests were normalized, giving the general response of the clay to various loading conditions. The assumption is made that the behavior of the clay is the dominant factor in the response of the system to the load applied on top of the aggregate. The response of the load on the surface of the aggregate was then compared to the generalized response for the load on the clay alone, resulting in an effective loading condition on the clay. The effective loading condition for systems with and without a geotextile were then compared.

A total of 15 tests were performed with various loads on various sizes of loading plates placed directly on the clay. The relationship between the vertical displacement occurring between 10 and 50 cycles and the ratio of the peak stress divided by the clay shear strength is shown on Figure 5. The relationship can be represented fairly accurately with a single line with no apparent skewness caused by peak load or plate size. Therefore, a reasonable estimate of the ratio of the peak stress to clay shear strength can be made if the change in deflection between 10 and 50 cycles is known. It should be noted that edge effects are included in the analysis within the limits of the tests performed.

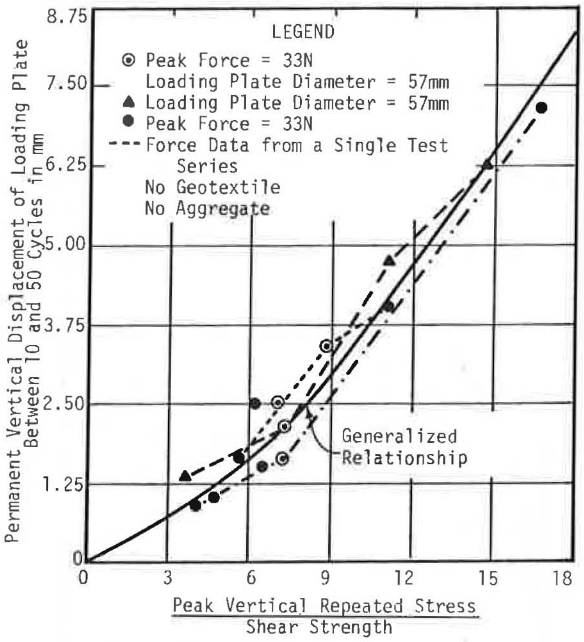

Fig. 5 Normalized Effect of Stress Level and Loading Plate Diameter

Figure 5 leads to the "effective area" concept used throughout the remainder of the analysis. The effective area is defined as the area of a circular plate placed directly on the clay which would result in the same displacement under the same total peak force as the actual load on the actual loading plate placed on the surface of the aggregate. Definitions for "effective stress" and "effective radius" follow similar logic.

In making these definitions, it was necessary to make some basic assumptions about the behavior of the system. The assumptions are made that the stress is transmitted through the aggregate and geotextile in a fashion that makes the stress on the clay appear as though it were being applied by a rigid circular plate. In other words, the stress is applied to the subgrade over a circular area that is depressed uniformly. The stress is in fact spread out over the clay surface, the deformed surface is dish shaped and the maximum displacement of the clay surface is less than that of the loading plate. The assumption is therefore not good, and the absolute value of any answer obtained would be suspect. However, the shape of the stress distribution and deformed surface should be similar between tests with and without a geotextile; hence, the assumption should lead to reasonably accurate comparisons between these two conditions. On larger scale tests, steps could be taken to correct for the inaccuracies in the assumption.

3.4.2 Test Results

Following the concept presented above, the effective parameters were developed for each test. The effective radius versus aggregate depth is shown on Figure 6. Each test in the comparison had a loading plate diameter of 38mm, therefore, the relationships normalized by loading plate radius are identical.

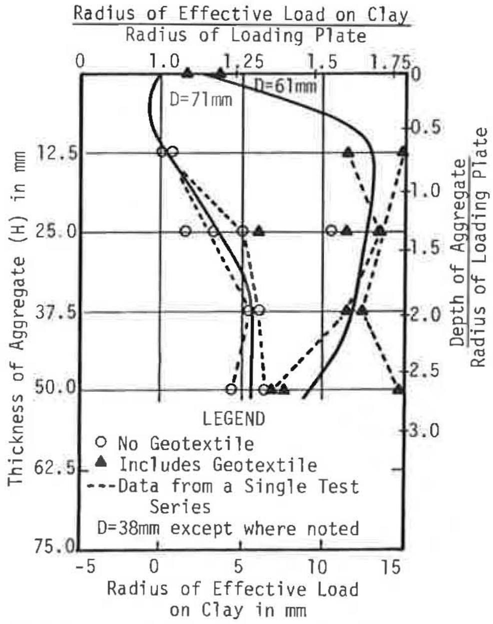

Fig. 6 Radius of Effective Load on Surface of Clay

The effective radius in systems with a geotextile was significantly greater than the effective radius in equivalent systems without a geotextile for most aggregate thicknesses used. This means that the presence of the geotextile causes the load to be distributed more widely than with the aggregate alone. Previously, it was noted that the systems with a geotextile were only slightly influenced by the drum effect; hence, it appears reasonable that the geotextile either acts as a tension member allowing the aggregate-geotextile combination to carry tension and bending, and/or the geotextile creates a confining pressure in the aggregate, changing its load distribution properties.

The effect of the geotextile appears to become less significant as the thickness of the aggregate increases. As described earlier, this would also be expected in field situations and was noted in larger scale laboratory tests by Kinney (1979). The results of this test may, however, overestimate the effect. The test results show some stabilization effect with no aggregate. This is probably due to the flexural stiffness and thickness of the geotextile in the small scale tests. This effect could be significant at all depths in the test but should be insignificant at all depths in the field. In addition, the test is small and as the thickness of the aggregate increases the size of the effective area increases and the boundary conditions become more significant. The boundary conditions are included in the normalizing procedures; however, the actual stress distribution probably extends outside the radius of the largest loading plate used. Therefore, the effects of the boundary conditions are probably underestimated for tests with a large effective radius.

It is interesting to note that in tests without a geotextile the effective radius is the same for no aggregate and for 12mm of aggregate. This is probably caused by a combination of two factors. The effective area concept may underestimate the influence of the aggregate, and/or 12mm of aggregate may not effectively distribute the stress from the loading plate outside the loaded area. The effective area may be underestimated for several reasons. At small aggregate thicknesses the deformed shape of the interface is more pronounced, which causes lateral spreading and a reduction in aggregate thickness. Since the aggregate thickness is decreased, the displacement of the clay is less than that measured, which results in an underestimate of the effective area. It is also possible that the effect of the lateral spreading allowed by the aggregate, which was restrained by the loading plate placed directly on the clay, is enough to negate any effect of the load distribution through the aggregate. In either case the response of the system to load was not improved by the addition of 12mm of aggregate and a proportional response should be anticipated in the field.

4. CONCLUSIONS

The test results and analyses presented herein provide valuable insight into the behavior of geotextile reinforced unsurfaced roads. The following conclusions were reached regarding the test results:

* Geotextiles act as structural reinforcement to the aggregate, causing it or the combination to distribute the load over the subgrade. This is true even if the geotextile does not extend outside the area of direct influence of the applied load.
* The effect of the geotextile diminishes with greater thicknesses of aggregate.
* Significant deformation appears to be required for the geotextile to act as a reinforcement, and additional deformation accentuates the beneficial effects.

These concepts can be extended to the field conditions if caution is used. The numerical data cannot be extrapolated directly to the field because of the differences in scale, the boundary conditions in the test, and the inaccuracies in the analysis techniques.

The testing technique and method of analysis appear to be valuable research tools and the work should be continued, but on a large scale. Full scale tests are desirable but expensive and time consuming. Tests performed in a tank about 1.22m square with .6m of clay, up to .3m of a pea gravel sized crushed stone aggregate, and loading plates on the order of 76 to 33mm in diameter would provide very valuable information. This scale is large enough to be meaningful for extrapolation and yet manageable from a cost and time of testing standpoint. The square configuration is suggested to allow studying the effect of the three dimensional wheel load placed in a two dimensional rut.

ACKNOWLEDGEMENTS

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REFERENCES

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