Large-Scale Model Tests of Geocomposite Mattresses over Peat Subgrades

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Prefabricated flexible polymeric soil confinement systems (called geoweb or geocell mattresses in this paper) hold great promise for increasing the trafficability and load-bearing capacity of thin granular bases placed over very compressible subgrades such as peat. A large-scale model test program was undertaken to compare the load-deformation performance of gravel-infilled geoweb/geocell mattresses and unreinforced gravel bases over peat under plane-strain static loading. In this investigation the geoweb mattress reinforcement was nonperforated plastic strips ultrasonically welded together (geoweb). The geocell reinforcement was constructed from strips of polymeric mesh (geogrid) attached by metal bodkins. Tests showed that the geocomposite mattresses significantly improved the load-bearing capacity of the gravel base layer in comparison with equivalent depths of unreinforced gravel bases. The stiffer geoweb construction gave a greater load-bearing capacity at a given rut depth than did the less stiff geocell construction. In addition, tests showed that the reinforcing effect due to the geocomposite construction of the geoweb was initiated at a lower rut depth than was that due to the geocell structure. Comparisons between geoweb-reinforced gravel bases and unreinforced bases showed that the geoweb composites were equivalent to about twice the thickness of unreinforced gravel bases. For comparison purposes, the study also presents the results of reinforced tests using single layers of geotextile and geogrid polymeric reinforcement placed at the gravel base–peat interface.

Prefabricated flexible polymeric soil confinement systems (called geoweb or geocell mattresses in this paper) hold great promise for increasing the trafficability and load-bearing capacity of thin granular bases over weak subgrades.

The potential of near-surface confinement systems to enhance granular bases was first demonstrated in tests carried out by the U.S. Army Corps of Engineers at the Waterways Experiment Station (WES) in the late 1970s (*1*). Prototype tests were carried out using plastic tubes 300 mm deep arranged to form a three-dimensional mattress over soft clay subgrades that had a California bearing ratio (CBR) of 1. The cellular mattress was infilled with sand and subjected to repeated passes of truck wheel loads. This reinforcement scheme was seen to generate wheel ruts under cumulative axle loads equivalent to the performance of unreinforced sand bases 500 mm thick (i.e., 40 percent saving in granular fill). Significant savings were also reported in a similar study at WES that used a cellular grid fabricated from slotted aluminum sheeting (*2*). Variables such as cell dimensions, cell material, and sand infill density were subsequently investigated at WES to optimize these systems for beach stabilization under vehicle loadings (*3, 4*). These studies also concluded that polymeric material may be effective in reinforcing near-surface soil confinement systems for expedient roadway construction over subgrades other than sand. The soil confinement concept was realized commercially with the introduction of a product called "Geoweb" constructed from 200- or 100-mm-wide nonperforated high-density polyethylene strips ultrasonically welded together to give a durable cellular mattress (*5*).

More recently, researchers at Sunderland Polytechnic U.K. have reported the results of model tests carried out with geoweb mattresses constructed over subgrades of two different stiffnesses (*6, 7*). The mattresses were constructed from 200-mm-thick geoweb infilled with a granular material. Reinforced and unreinforced test configurations were subjected to repeated static loading and plate bearing tests with a plate 300 mm in diameter. The tests showed that the reinforced sections significantly outperformed the unreinforced sections. For example, unpaved reinforced sections with poorly graded granular infill and a firm subgrade recorded a cumulative vertical deformation after about 104 load applications that was 50 percent of that recorded for the comparable unreinforced test. For a similar pair of test configurations with a soft subgrade, the data indicate that after 104 load applications the reinforced system recorded only 40 percent of the deformation recorded by the corresponding unreinforced configuration. These researchers also measured the vertical bearing pressures at the geocomposite-subgrade interface. They found that vertical stresses at these locations were significantly reduced for the reinforced sections, indicating that the reinforced base layers were more effective in distributing surface loads over a wider subgrade area. Finally, the test data showed that permanent deformations and vertical interface stresses for reinforced sections over soft subgrades were further reduced by using a well-graded granular fill.

Geoweb mattress composites have been used in practice to provide cost-effective road bases over compressible terrain, including soft organic clays (*8*, p. 81) and landfills (*9*), and to stabilize ballasted track (*10*).

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GEOWEB AND GEOCELL REINFORCEMENT MECHANISMS

The mechanisms that are responsible for the improved capacity of geocomposite mattresses are complex, and at present no analytical models exist to predict load-deformation behavior of these systems where they are constructed over very compressible terrain. Nevertheless, qualitative features of reinforcement mechanisms have been identified (*11, 12*). In simple terms, the cellular reinforcement in these systems improves the load-deformation behavior of the infilled soil through lateral confinement. Lateral spreading of reinforced base materials is resisted by hoop stresses in the cell walls and passive resistance developed in adjacent cells. Penetration of base materials in soft subgrades is reduced by the combined effect of high lateral confining stresses and soil–cell wall friction. Granular bases that have insufficient bearing capacity can develop adequate shear capacity under static or repeated load when confined in this manner. In pavement systems, the geocomposite mattresses increase the flexural stiffness of the structure and distribute surface loadings over a wider area at the pavement structure–subgrade interface.

OBJECTIVES

The principal objective of the current study was to investigate the static load-deformation behavior of geoweb and geocell mattress composites constructed over peat subgrades. A second objective was to evaluate the performance of these geocomposites by comparing the test results with those recorded for unreinforced sections and gravel bases reinforced with a single layer of geogrid or geotextile at the gravel-peat interface.

GENERAL

The general test arrangement is shown in Figure 1. Reinforced and unreinforced test sections were constructed in a concrete pit measuring 2.4 m wide by 3.6 m long by 1.8 m deep. An overview of the test facility is given in Figure 2. Reinforced and unreinforced gravel base layers varying from 150 to 600 mm in depth were constructed over a reproducible artificial peat subgrade nominally 1 m thick. A hydraulic actuator was used to apply a series of static load increments to a 200-mm-wide beam spanning the width of the test pit.

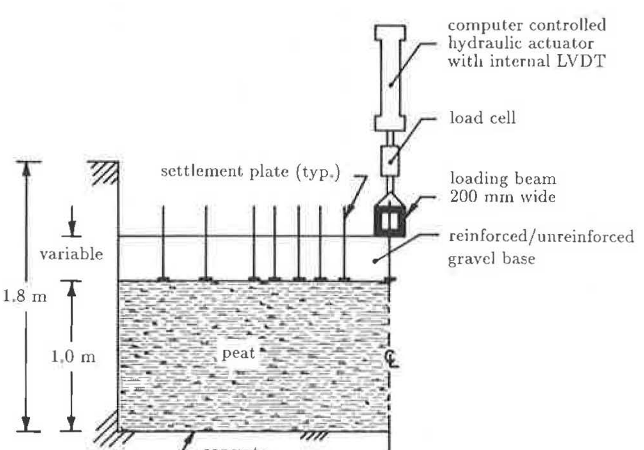

FIGURE 1 General test arrangement.

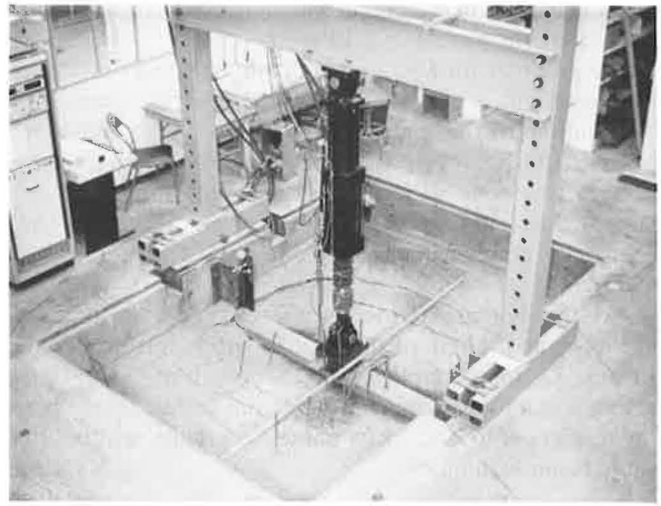

FIGURE 2 Overview of RMC test facility.

The current study is focused on the load-deformation behavior of two types of near-surface soil confinement schemes that include polymeric materials:

- Geoweb-gravel mattresses and
- Geocell-gravel mattresses.

The performance benefit due to these geocomposite constructions was determined by comparing these systems with unreinforced systems constructed from the same soil materials. In addition, the performance of the geocomposite mattresses was compared with that observed in a number of similar tests of single-layer polymeric sheet reinforcement. A number of these tests have been previously reported by the second author (*13, 14*).

CONSTRUCTION

Soil Materials

For the tests on reinforced and unreinforced systems reported in this paper, a very compressible subgrade comprised of a finely fibrous horticultural sphagnum peat with a low degree of decomposition was used. For each test the peat was reconstituted by adding water and then dispersing the peat-water mixture with compressed air through a system of perforated pipes at the bottom of the test facility. Preconsolidation of the peat subgrade before fill placement was achieved by downward drainage through the same system of perforated pipes. Typical moisture content of the peat before fill placement was 750 ± 50 percent. Shear vane strengths were 3 ± 1 kPa.

The granular fill was a good quality crushed limestone aggregate with a top size of about 20 mm. The grain size distribution for this material is shown in Figure 3. Where possible, the aggregate was placed in 150-mm lifts. Compaction was done with a gasoline-driven vibrating plate tamper that had a mass per unit area of 150 kg/m^2. The compacted gravel had an average density of 1950 ± 50 kg/m^3.

As a result of fill placement, some settlement and increase in the shear strength of the peat subgrade was observed. In Test 12, for example, a 300-mm depth of gravel base resulted in a total settlement of 60 mm and an increase in shear strength to 6 ± 1 kPa in the underlying peat before static beam loading.

Geoweb-Gravel Mattress Tests

Three tests were carried out using a geoweb-gravel composite construction. The geoweb reinforcement was nonperforated polyethylene strips, 100 and 200 mm wide, ultrasonically welded together to give an open-cell construction that had a cell area of 265 cm^2. An example of the 200-mm-deep geoweb reinforcement is shown in Figure 4. The tensile capacity of the reinforcement strips in isolation is controlled by the welds, which have a seam tensile peel strength of about 7 kN/m (5). One test was carried out using a geoweb reinforcement 100 mm deep infilled with gravel and covered with a 50-mm layer of the same compacted fill. A second test used the same fill in a cell mattress 200 mm deep and included a compacted gravel fill cover 100 mm deep. The second test was repeated to confirm load-deformation behavior. The depth of cover in each test was selected to bring the composite gravel base course thickness up to 150 or 300 mm, which represent standard base thicknesses for a large number of reinforced and unreinforced tests that have been carried out at the Royal Military College (RMC) of Canada. In actual expedient road construction it would be reasonable to place a similar depth of unbound gravel to protect the confinement system from direct traffic loading. For brevity in the following text, these tests are referred to as 150- and 300-mm geoweb mattress tests. Finally, the reinforced sections included a layer of lightweight woven polypropylene filter fabric at the gravel-peat interface to act as a separator during construction (geotextile weight = 244 g/m^2).

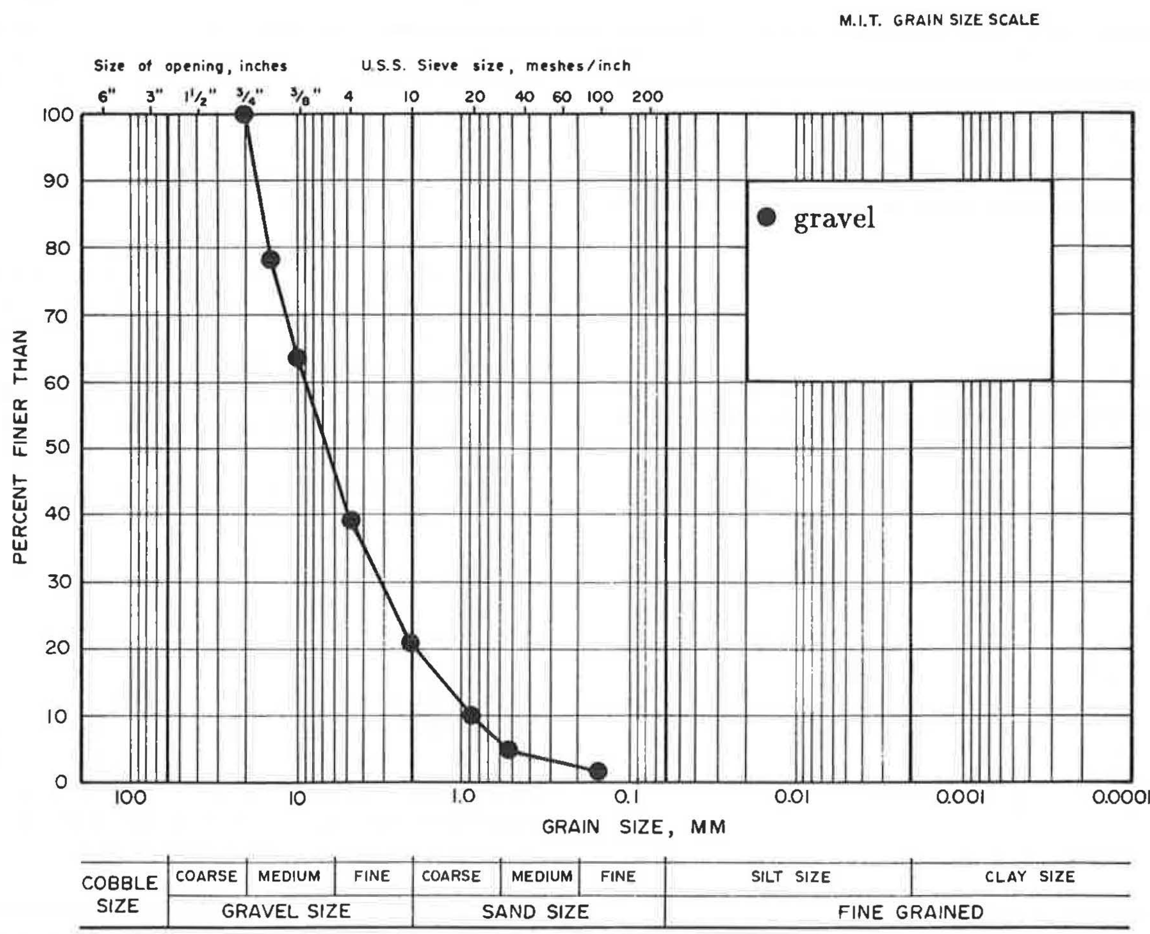

FIGURE 3 Grain size distribution of gravel fill.

Geocell-Gravel Mattress Test

A single test was carried out using a geocell-gravel mattress configuration manufactured in-house. The soil confinement material in this instance was 150-mm-wide strips of relatively high-strength open-grid reinforcement constructed from oriented high-density polyethylene (Tensar SR2 geogrid). The in-isolation load-strain-time properties of this material are well documented (*15*), and it has an index tensile test capacity of about 65 kN/m (*16*). Reinforcement strips were laced together using vertical steel bodkins to give cell areas of approximately 260 cm^2. The expanded geocell mattress was placed over a Tensar SS2 geogrid oriented with its strong direction in the plane-strain direction of the test. The original intention was to have this layer act as a gravel-peat separator during construction. The mattress was infilled and covered with 150 mm of compacted gravel fill to give a total composite thickness of 300 mm.

Single-Layer Reinforcement Tests

For comparison purposes, the results for gravel bases 300 mm thick reinforced with a single layer of geosynthetic material are also presented. Two tests employed a single layer of Tensar SS2 geogrid at the gravel-peat interface and the third a lightweight woven polyamide geotextile at the same location (geotextile weight = 229 g/m^2).

Unreinforced Tests

A total of five unreinforced tests were carried out to evaluate the load-deformation performance improvement due to geosynthetic composite construction. The unreinforced tests included 0, 150, 300, 460, and 600 mm of gravel base material.

TESTING PROGRAM

In each test a series of monotonically increasing static loads was applied to the beam seated directly on the gravel base layer (or directly on the peat for the unreinforced test with no gravel base material). The beam was loaded using a MTS computer-controlled closed-loop electrohydraulic actuator. Each load was sustained until the vertical deformation rate became less than 0.02 mm/min. This initial loading sequence was discontinued after a total vertical beam displacement (rut depth) of 200 mm had been achieved. The initial loading procedure represents a standard method that the authors have adopted over a period of several years; it has been employed in numerous similar tests to investigate a variety of geosynthetic composite structures at RMC (*13, 14*). The 200-mm rut depth criterion was selected simply because it represents a tire rut depth that may impede vehicular traffic in a comparable field case. Depending on the test, one of several different loading strategies was adopted after this initial loading

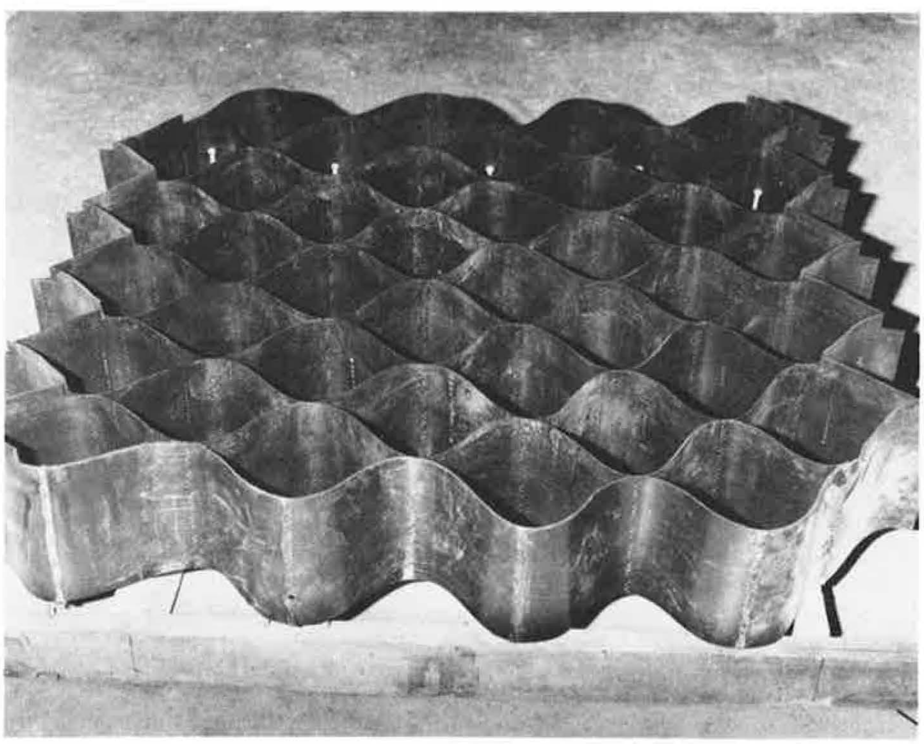

FIGURE 4 Expanded 200-mm-deep geoweb reinforcement material.

sequence. For instance, some tests were subjected to five cycles of the (previous) maximum load and then the rut was backfilled. After backfilling, the beam was again cycled at the same load level for five cycles and then subjected to a series of greater static loads. In some thin-layer unreinforced tests, the sections failed by punching before the displacement rate criterion or 200-mm rut depth had been achieved. For this reason, backfilling had to be carried out before further loading could be undertaken. Because of the different backfilling and load histories after the initial loading program, it is not possible to compare test results beyond the initial loading sequence. The second-stage loading programs of two selected tests are given later in the paper to illustrate the influence of rut backfilling and repeated static loading on the performance of geocomposite mattress constructions. A summary of the test configurations repeated in the current study is given in Table 1.

TEST RESULTS

Load Deformation

The results of (initial) load-deformation measurements taken for all tests are shown in Figures 5–7. Figure 5 shows the results of the geoweb mattress tests along with the results of the five unreinforced (control) tests. As expected, the unreinforced tests show a systematic increase in load capacity at a given rut depth with increasing gravel base thickness. It should be noted that the unreinforced tests with 0, 150, and 300 mm of gravel base were at or very near punching failure during the last applied load increment. For example, the 0.02-mm/min deformation rate criterion for the 300-mm unreinforced section could not be achieved after 200 mm of deformation. All other tests reported in this study were able to support sustained load increments after 200 mm of deformation and in many instances indicated system strain hardening.

The 150-mm geoweb mattress test (Test 1) gave a load-deformation response comparable to the response of the 300-mm unreinforced test (Test 9). Similarly, the 300-mm geoweb mattress tests (Tests 2 and 12) gave load-deformation behavior that falls between that of unreinforced base courses 460 mm thick and that of unreinforced base courses 600 mm thick (Tests 10 and 11).

Figure 6 is a plot of the results of reinforced tests of a 300-mm geocell mattress (Test 3) and a 300-mm gravel

TABLE 1 SUMMARY OF TESTS

Test No.	Composite Base Thickness (mm)	Description
1	150	geoweb mattress
2	300	geoweb mattress
3	300	geocell mattress
4	300	SS2 Geogrid at gravel/peat interface*
5	300	(repeat of 4)
6	300	geotextile at gravel/peat interface
7	0	unreinforced*
8	150	unreinforced*
9	300	unreinforced*
10	460	unreinforced*
11	600	unreinforced
12	300	geoweb mattress (repeat of 2)

*Taken from Jarrett (13, 14).

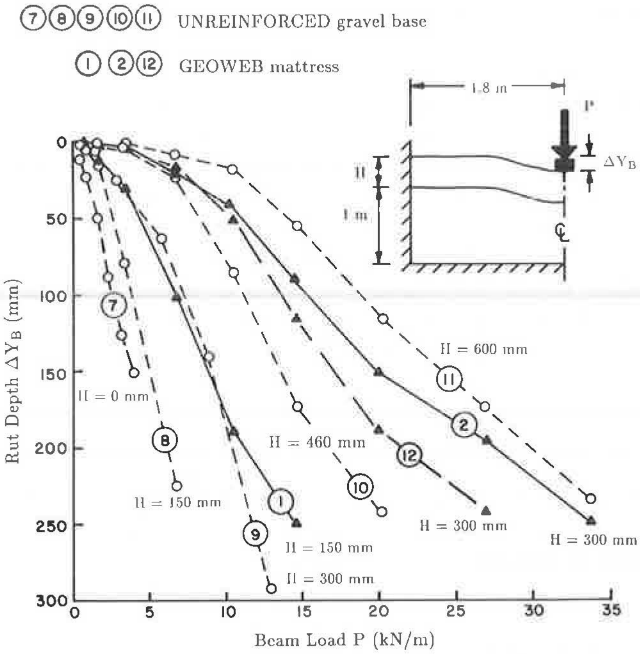

FIGURE 5 Load-deformation results for tests on geoweb mattress and unreinforced gravel base.

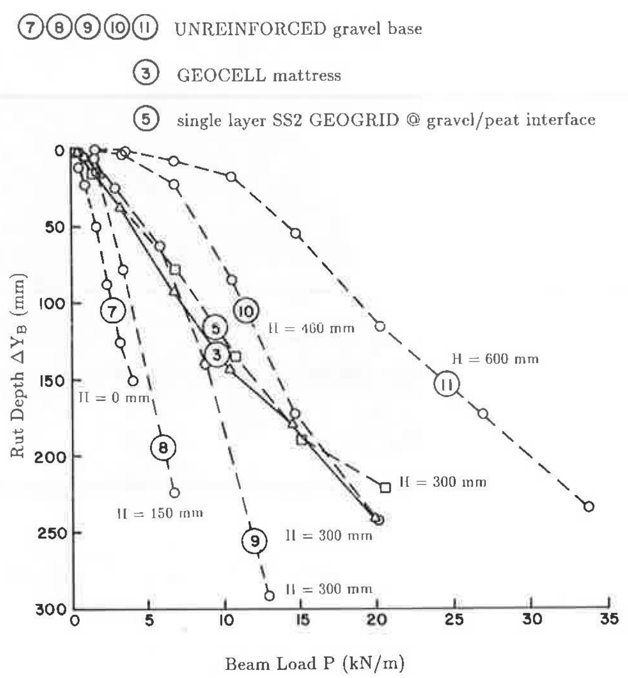

FIGURE 6 Load-deformation results for test on geocell mattress, gravel base with a single layer of geogrid reinforcement, and unreinforced gravel base.

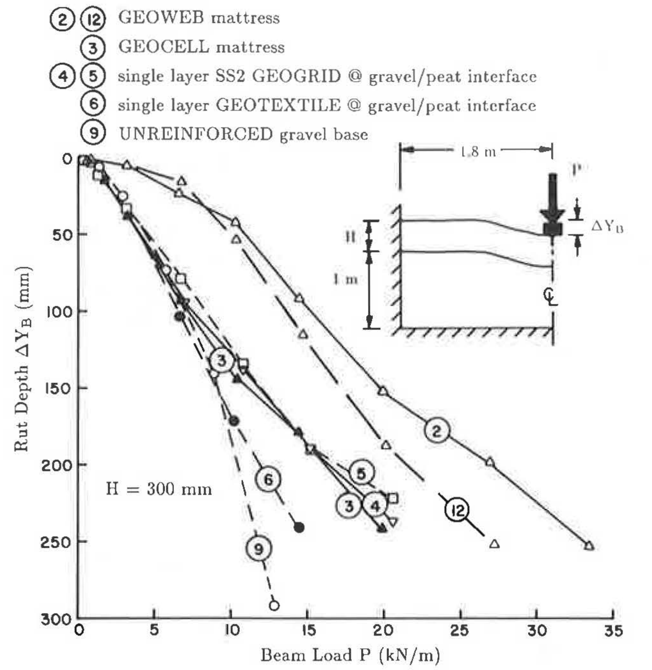

FIGURE 7 Comparison of reinforced and unreinforced tests with 300 mm of gravel base.

base reinforced with a single layer of SS2 geogrid at the gravel-peat interface (Test 5). The horizontal reinforcement in both of these tests was Tensar SS2, oriented in the same direction for both configurations. Surprisingly, both reinforced tests show similar load-deformation behavior indicating that, in this study, the geocell soil confinement system in conjunction with a single layer of SS2 geogrid offered no additional system capacity over that offered by the single layer of geogrid alone. Both tests gave load-deformation responses that were between the 300- and 460-mm unreinforced test results. At a 200-mm rut depth both reinforcement schemes gave load capacities comparable to unreinforced tests with 1.5 times the depth of compacted gravel.

The results of tests with 300 mm of gravel base are plotted in Figure 7. A variety of reinforcing systems, including single layers of polymeric reinforcement and geocomposite mattresses, is shown in this figure. All reinforced sections were stable at 200 mm of vertical deformation in contrast with the unreinforced test (Test 9), which was terminated early because of punching failure. The relative performance benefit of the reinforcing schemes is illustrated in the figure. The least improvement was indicated by the test with a geotextile reinforcement (Test 6) and the best by the 300-mm geoweb mattress tests (Tests 2 and 12). A repeat of the 300-mm reinforced test with SS2 geogrid is also plotted in the figure. The two nominally identical constructions gave sensibly equivalent load-deformation behavior indicating that test procedures were reproducible for the single-sheet reinforcement schemes.

Tests 2 and 12 indicated a similar load-deformation response up to 50 mm displacement but diverged somewhat with further application of load. This discrepancy is thought to be due to the relative difficulty of controlling uniform compaction of the gravel within the 200-mm-high cells of the geoweb composite. Figures 5–7 also illustrate that, unlike the single-layer and geocell mattress reinforcement methods of construction, the geoweb mattresses showed improved load capacity over similar thicknesses of unreinforced gravel at low rut depths. For example, Tests 3–5 indicated load capacity improvement with respect to the same depth of unreinforced gravel base after about 100 mm of vertical displacement had occurred. In contrast, the stiffer geoweb mattress configurations showed improvement after 10 to 20 mm of vertical displacement. The relative improvement due to geocomposite mattress construction is illustrated in Figure 8, which shows "equivalent" depths of unreinforced gravel base course for the same beam load and rut depth under first-time loading. For example, Curve 1 indicates that a 150-mm geoweb composite is equivalent to about 300 mm of unreinforced gravel base (a factor of 2 improvement). Similarly, the 300-mm geoweb composites over a range of rut depths are equivalent to between 500 and 600 mm of unreinforced gravel base. The relative improvement associated with the 300-mm geoweb composites is somewhat less than that inferred for the 150-mm geoweb composite as a result of the better compaction that was achieved in the shallower construction where the geoweb cells were only 100 mm high.

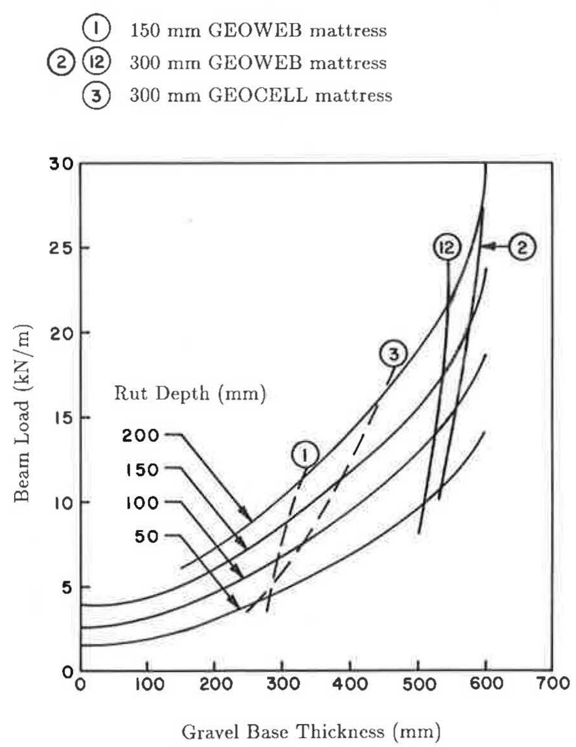

FIGURE 8 Equivalency chart for geocomposite mattress tests and unreinforced gravel bases (initial loading only).

ADDITIONAL OBSERVATIONS

At the end of each reinforced test reported in the current study, the geosynthetic reinforcements were excavated to determine any evidence of rupture. No rupture of geosynthetic reinforcements was observed in any test, nor was there any indication of tearing at the welded seams in the geoweb mattress tests or at the bodkin connections in the geocell mattress test.

DISCUSSION OF RESULTS

The relatively better performance of the geocomposite mattresses compared with that of single-sheet reinforcement schemes is consistent with the concept of greater soil confinement in geocomposite mattress construction. The performance difference of the relatively stiffer 300-mm geoweb mattress and the comparable 300-mm geocell mattress indicates that soil confinement is further enhanced through stiffer cell walls in geocomposite mattresses of similar cell dimensions. The welded geoweb strip construction was intrinsically more effective in reducing lateral spreading of the gravel fill under load than was the more flexible geogrid-and-bodkin construction. For example, in all reinforced tests, including the single-layer reinforcement tests, the gravel base course was observed to pull away from the sides of the test facility located 1.8 m from the beam. However, the geoweb mattresses showed this effect relatively early in the initial loading program, indicating that soil confinement was more effective in these configurations. The greater stiffness of the expanded 300-mm geoweb mattress compared with that of the comparable 300-mm geocell mattress before installation was visually apparent to the authors. The inherent greater flexural stiffness of the geoweb/mattresses in isolation may account for the improved load-deformation behavior of these geocomposites at low load levels. In addition, it was noticed that the gravel infill and cover were more easily compacted when geoweb mattresses were used. Nevertheless, it may be difficult to achieve uniform levels of compaction through the entire depth of a geoweb composite when aggregate with a 20-mm top size is used as infill for the 200-mm-deep geoweb material. The relative flexural stiffness of gravel base layers in the current investigation can be seen in Figure 9, which shows normalized vertical deformations recorded at the gravel-peat interface at the end of the initial loading program. The data indicate that the footing loads are distributed over a wider area for the geocomposite mattresses than for the unreinforced test and that this trend is more pronounced for the geoweb mattress construction.

On roads with gravel bases, vehicular traffic will cause any new base to rut. Conventional practice with these structures is to allow the rutting to occur during construction in order to mobilize the reinforcement capacity of the geosynthetic. Subsequently, the ruts are backfilled; this procedure is repeated until an acceptable level of surface deformation under traffic is achieved. The benefit of backfilling to system stiffness is shown in Figures 10 and 11. In Figure 11 the combined effect of backfilling followed by cyclic and static loading is seen as a further 100 mm of rutting at a beam load of 35 kN/m compared with an initial response of 240 mm at a beam load of 20 kN/m.

The current investigation has been restricted to the investigation of load-deformation of geocomposites and unreinforced gravel bases over very compressible subgrades (i.e., peat). At the time of writing, no comprehensive study of the influence of subgrade stiffness on the behavior of geocomposite mattress systems had been undertaken. A limited number of tests with relatively stiff subgrades have been reported in the literature, but they indicate only that bearing capacity of a geocomposite mattress increases with greater subgrade stiffness (*11, 12*). Recent work reported by the authors on single-layer reinforcement of coarse granular bases indicates that the relative performance ben-

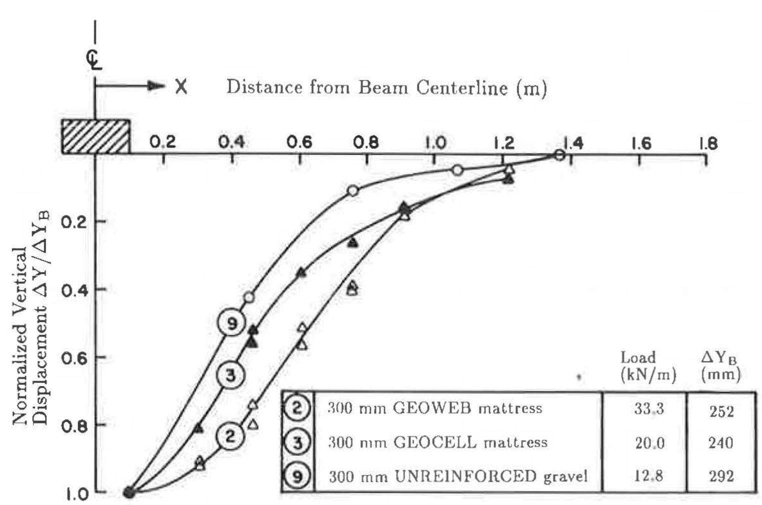

FIGURE 9 Deformation profiles at gravel base–peat interface for selected tests.

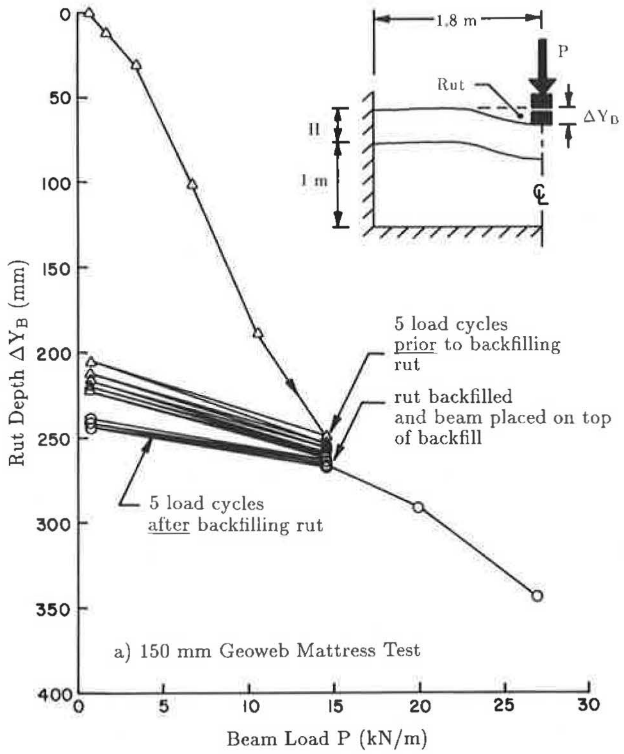

FIGURE 10 Load deformation for geocomposite mattress tests including backfilling and repeated static loading—150-mm geoweb mattress test.

efit of reinforced systems over that of comparable unreinforced systems diminishes with increased subgrade stiffness (*17, 18*). It is possible that the high-deformation models employed in the current test program show both geocomposite mattresses and single-sheet geotextile geogrid reinforcement schemes at their best. More work remains to be done to investigate the performance benefit of geocomposite mattresses constructed over subgrades that are more competent than the ones reported here.

CONCLUSIONS

A series of large-scale static tests was undertaken to investigate the load-deformation behavior of geocomposite mattresses constructed over a compressible peat subgrade and to compare this behavior with that of comparable unreinforced gravel bases and gravel bases reinforced with a single layer of geotextile or geogrid at the gravel-peat interface. The major conclusions from this study are summarized as follows:

1. All reinforced gravel bases showed significant load capacity improvement at large rut depths compared with similar thicknesses of unreinforced gravel bases.
2. The geocomposite mattresses constructed from still nonperforated polyethylene geoweb showed the greatest performance improvement of all geocomposite reinforce-

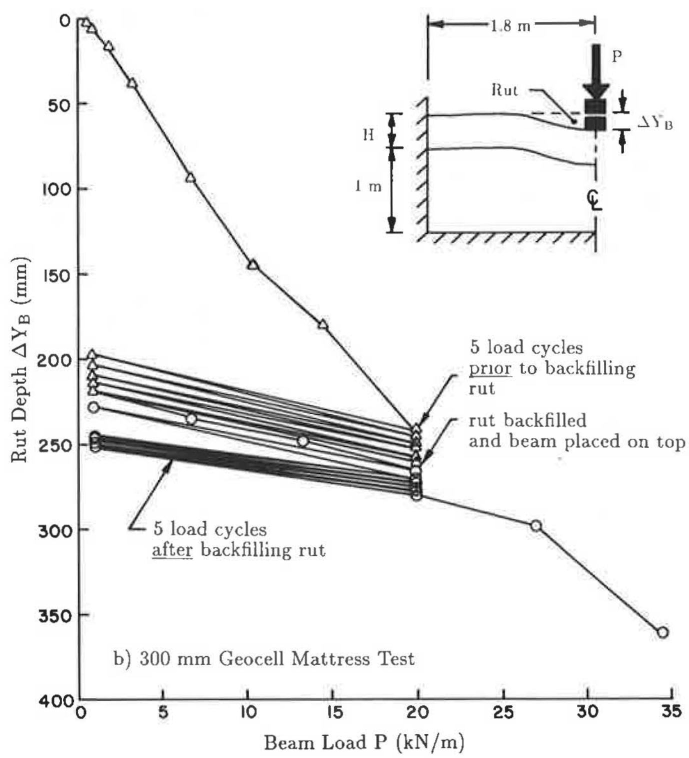

FIGURE 11 Load deformation for geocomposite mattress tests including backfilling and repeated static loading—300-mm geocell mattress test.

ment schemes investigated. The enhanced soil confinement due to the stiff geoweb cellular construction is thought to be responsible for this.

3. A test of a relatively flexible geocell construction and and an SS2 geogrid as a gravel-peat separator gave essentially the same load-deformation behavior as reinforced tests using only the SS2 layer.

4. Over a range of rut depths (up to 200 mm) the 150-mm-thick geoweb mattress gave a load-deformation response equivalent to that of unreinforced configurations with about 300 mm of gravel base material. Similarly, 300-mm-thick geoweb composites are considered equivalent to unreinforced gravel bases 500 to 600 mm thick.

5. The performance benefit due to the geoweb mattress construction was observed to occur at relatively low rut depths of 10 to 22 mm, which were significantly lower than the 100 to 150 mm of beam displacement required to mobilize the reinforcing effect of the other geocomposite configurations investigated.

6. The influence of subgrade stiffness on the relative performance benefit of geocomposite mattresses over similar unreinforced configurations requires investigation.

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