Laboratory Evaluation of Geosynthetic-Reinforced Pavement Sections

IMAD L. AL-QADI, THOMAS L. BRANDON, RICHARD J. VALENTINE,
BRUCE A. LACINA, AND TIMOTHY E. SMITH

Preliminary experimental and analytical investigations were conducted to evaluate the performance of pavements with and without geotextile or geogrid reinforcement materials. Four pavement sections were tested: one unreinforced section that served as a control and three sections reinforced with either one of two geotextiles or a geogrid. The pavement sections were constructed to model a typical secondary road in Virginia built over a weak granular (silty sand) subgrade material. Loading of the pavement sections was accomplished through the use of a computer-controlled pneumatic system that delivered approximately 55 kPa through a 30-cm rigid plate at a frequency of 0.5 Hz. The resulting displacement of the pavement surface was monitored by an array of linear variable displacement transformers. The performance of each pavement section was evaluated as a function of the applied number of cycles, the resulting surface deflection profile, and the layer deflection profile. It was concluded that geosynthetics can substantially improve the performance of a pavement section constructed on a subgrade soil with a low California bearing ratio. Also the reinforcing mechanisms of geogrids and geotextiles are different.

Geosynthetics have long been recognized as materials that can significantly improve the performance of paved and unpaved roads, especially those constructed on weak subgrades. Geogrids and geotextiles are the two types of geosynthetic most widely used in pavement systems. Geotextiles consist of synthetic fibers that are either woven into flexible, porous sheets or matted together in a random, nonwoven manner. Goegrids are usually manufactured from polypropylene, high-density polyethylene (HDPE), or high-tenacity polyester.

The first industrywide design standards for geotextiles were not established until Giroud and Noiray's landmark 1981 paper (*1*), almost 50 years after their first documented application in the United States. Until the mid-1980s the design of geosynthetic-reinforced pavements was poorly documented and based on empirical evidence. In 1985 the *Geotextile Engineering Manual* was published by FHWA (*2*). In 1990 Koerner published *Designing with Geosynthetics*, which explained the mechanical properties of geogrids and geotextiles on the basis of contemporary information (*3*).

The key functions of geotextiles in improving flexible pavement performance are separation, reinforcement, and filtration. Reinforcement is the most important function of geogrids. Through separation geotextiles inhibit two mechanisms that tend to occur simultaneously over time in pavements: soil fines attempt to migrate into the voids between the base course stones, thereby affecting the drainage capability of the pavement system and its structural capacity; and the stone attempts to penetrate into the soil, compromising the strength of the stone layer (*2*). In order to achieve proper separation geosynthetics should be designed for burst resistance, tensile strength requirements, puncture resistance, and impact resistance.

Through reinforcement geosynthetics distribute a concentrated load over a larger area of the subgrade and improve the strength of pavement systems built on weak soil or other disjointed and separated material (*3*). The dual mechanisms of reinforcement are a further spreading of the load to the subgrade, providing a more stable support condition; and development of an appreciable amount of tensile stress resistance in the fabric. If the geosynthetic has a sufficiently high tensile modulus, the tensile stress resistance may reduce the plastic deformation of the subgrade soil caused by vehicular loading (*2*).

Finally through the filtration mechanism geosynthetics may inhibit generation of excess pore pressures in the subgrade and may prevent migration of the subgrade fines migration into the base or subbase. The pore water pressure in the soil usually increases as a result of dynamic loading. At the point at which the pore pressure is greater than the total stress of the soil, a soil slurry is formed. When designed with the correct permittivity, geosynthetics filter the soil particles and pore pressure is allowed to dissipate. Christopher and Holtz (*2*) reported a case in which geotextiles were applied incorrectly and designed inadequately, which led to pore water pressure development and pumping in subgrades.

Reports from various studies indicate that pavement strength can be increased by placing geosynthetics at the hot-mix asphalt (HMA) base course interface, in the base course layer, at the base course–subgrade interface, and in HMA overlays to strengthen existing pavements. Although the resulting improvement in the pavement systems has not been well quantified, it has been reported that reinforced pavement strength increases as the position of the geosynthetic approaches the base course–subgrade interface (*4–6*). In general geosynthetics are said to increase initial stiffness, decrease creep, increase tensile strength, reduce cracking, improve cyclic fatigue behavior, hold cracked pieces together, and provide low life-cycle cost.

Many studies on the importance of geogrids have been reported recently (*1,5–12*). The studies conducted at the Royal Military College in the United Kingdom; the Ontario Ministry of Transportation and Communication in Canada; Gulf Canada, Ltd.; and the University of Waterloo (*4,7,8*) suggested that geogrids provide substantial savings in HMA thickness, double the number of load repetitions, prevent or minimize fatigue cracks in the HMA layer, and reduce permanent deformation in flexible pavement systems. Geogrid-reinforced pavement sections have been reported to carry three times the number of loads as conventional unreinforced pavements, and geogrid reinforcement allowed up to 50 percent reduction in the required thickness of the base course. Webster (*9*)

Department of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Va. 24061-0105.

evaluated the performance of geogrids in reinforcing flexible pavements, using a 134-kN single-tire load, to develop design criteria for reinforced flexible pavements used by light aircraft. He reported that using geogrid at the base course–subgrade interface would decrease the required base course thickness. This benefit was reported to decrease for stronger pavement sections.

Research on geotextiles has been less intensive. DeGiardiel and Javor (*13*) concluded from their study that the effectiveness of geotextiles increases with increasing deformation and suggested that a double layer of fabrics yielded the largest amount of subgrade strengthening. Resl and Werner (*14*) concluded from their study that the benefit of geotextiles is derived instead from their characteristics in separation, filtration, and drainage.

Case histories such as the Pan American Highway (*15*) have also shown the importance of the separation mechanism of geotextiles. Saxena (*16*) used pretensioned geotextiles to reduce potential rutting in a major roadway project in Florida. A field application combining both geotextiles and geogrids was reported to provide the benefit of both geotextile and geogrid mechanisms (*17*). Austin and Coleman (*10*) evaluated four types of geogrid, a geotextile, and a geogrid/geotextile for pavement reinforcement. The study showed that the geotextile performed better than the other systems, with the exception of one geogrid-reinforced section constructed on a subgrade with a higher California bearing ratio (CBR) value. The study emphasized the importance of geotextile as a separator.

In a comparison study of geotextile and geogrid performance, Barksdale et al. (*6*) reported that permanent deformation can be reduced substantially if geosynthetics are used on weak subgrades to reinforce thin pavement layers. The study suggested that under the testing conditions used the performance of geogrids is better than that of geotextiles and recommended using geotextiles in the middle of low-quality base course material. However the data in the report showed that if the geosynthetic did not mobilize its strength and separation was the mechanism that provided the performance enhancement (which is more likely), the geotextile would perform better. Prerutting was also found to improve the performance of geosynthetics. In all cases proper application is critical.

Field evidence suggests that both geogrids and geotextiles can improve the performance of pavement sections constructed on weak soil; however, it remains difficult to quantify the benefits that result from the application of these geosynthetics. In the absence of such quantification, a cost comparison is not possible. Also the mechanisms by which these materials enhance the performance of pavement sections is poorly understood.

The purpose of this ongoing research is to investigate pavement life-cycle improvement when geotextiles and geogrids are used to reinforce pavement cross-sections. Four pavement test sections were constructed to model typical secondary roads built over weak silty sand subgrades; one was a control section and the other three were reinforced with geosynthetics. Simulated traffic loads were applied and the performance of each test section was evaluated. This paper presents a detailed report of the experimental methods and a preliminary analysis of the results.

EXPERIMENTAL PROGRAM

Four different pavement sections were constructed in a reinforced concrete testing pit. One test section was unreinforced (the control section), two were reinforced with geotextiles, and one was geogrid-reinforced. The test sections were built to model typical secondary roads constructed on a weak granular subgrade material. Following the construction of each section the pavement surface was dynamically loaded via a rigid plate and the resulting displacement was continuously monitored and recorded. The following paragraphs describe the composition and construction of the test sections and the pavement loading system.

Test Facilities

The testing program was conducted at Virginia Polytechnic Institute and State University's (Virginia Tech's) Price's Fork Geotechnical Research Center. The Instrumented Test Facility at the research center was constructed for previous experimental programs (*18,19*). The facility's dimensions are 3.1 × 1.8 × 2.1 m deep, with the test pit floor located 1.2 m below grade. A schematic cross-section of the pit and pavement is shown in Figure 1. Access to the pit is gained by a ramp that facilitates soil placement and lift construction. The test pit walls are constructed of reinforced concrete. A load frame secured to the top of the east and west walls of the test pit provides a reaction force for the application of a vertical load of up to 62 kN. In this investigation, only 40 kN were required to load the pavement sections, representing dual-tire loading of an 80-kN axle.

Test Materials

The test sections consisted of a compacted silty sand subgrade, a well-graded gravel base course, and an HMA wearing surface. For the three reinforced sections, a geotextile or geogrid was placed at the subgrade–base course interface.

Subgrade Soil

The subgrade soil was Yatesville silty sand (YSS) obtained from alluvial deposits excavated during the construction of the Yates-

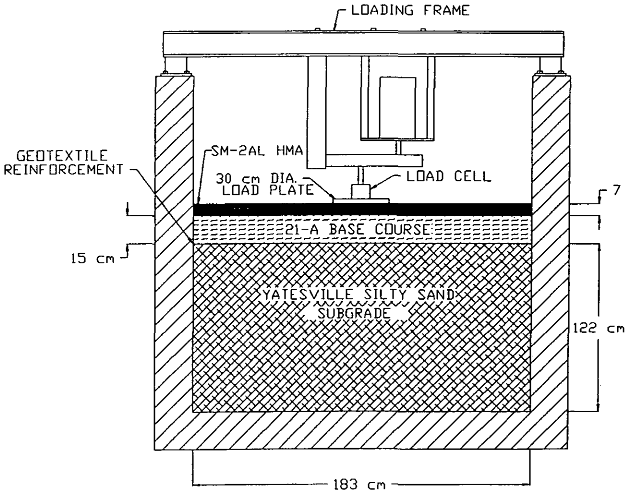

FIGURE 1 Schematic of test pit and pavement test section.

TABLE 1 Moisture-Density Relations for Yatesville Silty Sand (*18*)

Test Type	Compactive Effort (kN•m/m^3)	Maximum Dry Density (g/cm^3)	Optimum Water Content (%)
Mod. Proctor	2690	2.11	8.8
Std. Proctor	592	2.00	10.9
Low Energy	296	1.93	11.6
Very Low Energy	118	1.83	14.0

ville Lake Dam in Lawrence County, Kentucky. It is an A-4 soil, according to AASHTO classification, with a fines content of 40 to 47 percent. The fines are non-plastic, and the specific gravity (G_s) of its solids has been found to be 2.67. Moisture-density relations were established for a variety of compactive efforts, as summarized in Table 1.

The CBR (ASTM D1833-87) was used to characterize the subgrade soil index strength during the testing program. To place the lifts of YSS soil at a specific CBR instead of a standard dry density, it was necessary to evaluate CBR as a function of both compactive effort and the water content for that compactive effort (see Figure 2). To achieve this, two CBR (soaked) testing programs were devised and 43 tests conducted. Based on test results it was determined that it was possible to achieve any low CBR, modeling a weak subgrade material, given careful control of compactive effort and water content.

Base Course Aggregate

Granite aggregate was used to construct the base course in a trial test section. The base course aggregate met the Virginia Department of Transportation (VDOT) specifications for 21-A classification. The aggregate gradation is presented in Table 2. The material's moisture-density relationship was established by performing modified Proctor tests (ASTM D1557-91), and it was determined that the maximum dry density was 2.30 g/cm^3 at an optimum water content of 6.3 percent. The aggregate has a specific gravity of 2.81 and an absorption value of 0.4 percent (ASTM C97-90).

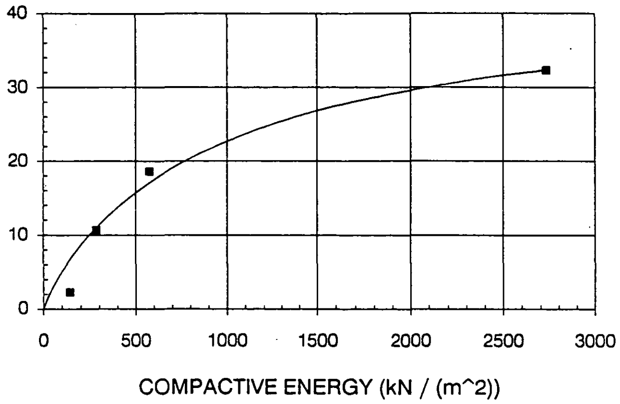

FIGURE 2 CBR as a function of compactive energy at optimum water content for Yatesville silty sand.

TABLE 2 21-A Base Course Aggregate Gradation

Sieve Size (mm)	Percent Passing (%)	Standard Deviation
50.8	100.0	0.0
19.1	90.0	0.8
12.7	74.6	2.9
9.5	65.4	2.7
4.75	48.9	2.2
2.36	39.6	1.9
0.60	28.1	1.4
0.30	19.8	1.4
0.15	13.9	0.8
0.075	7.4	0.6

HMA Wearing Surface

The HMA wearing surface used in the construction of the test sections met the VDOT material specification for SM-2AL, which is the same as that often used on secondary roads in Virginia. The aggregate used in this mix was a crusher-run dolomitic limestone. The asphalt content (AC-30) was 5.9 percent, HMA maximum specific gravity was 2.54, voids in the total mix were 4.5 to 5.1 percent, and voids in the mineral aggregates were 17.5 to 18.9 percent.

Geosynthetic Materials

Geotextile A and Geotextile B were used in two of the reinforced test sections. They have a woven structure and are manufactured from polypropylene. A biaxial geogrid was chosen to reinforce the third reinforced pavement section. This geogrid has a punched and sheet-drawn structure and is also manufactured from polypropylene. Table 3 summarizes the wide width strip tensile data for these geosynthetic materials, as provided by the manufacturers.

Pavement Section Design and Construction

The pavement test sections were designed to reflect the conditions typically encountered when constructing a secondary road over a weak subgrade material having a low CBR. To model these conditions, a subgrade section of YSS 1.22 m thick was compacted at a CBR of approximately 4 percent. The YSS subgrade was placed in uncompacted lifts 20 cm thick at a water content between 12.2 and 12.8 percent, which corresponded to the desired CBR value of 4 percent. Following placement the soil was tilled to break up soil clumps and then raked to a level surface. The

TABLE 3 Wide-Width Strip Tensile of Geosynthetics (ASTM D4595-86)

Type of Reinforcement	2% Strain (N/cm)	5% Strain (N/cm)	Ultimate (N/cm)
Geogrid	54	103	171
Geotextile A	39	89	256
Geotextile B	44	103	344

soil water content was again measured and if it was within acceptable limits the lift was compacted with a hand-operated Wacker model BPU 2440A compactor. A trial-and-error process yielded accurate estimates of the number of passes required to obtain the desired dry density, which was within the range of 1.85 to 1.89 g/cm^3. Each 15-cm-thick compacted lift was surveyed to determine total section thickness and evenness. To verify the water content and dry density each lift was evaluated by performing at least one sand cone test (ASTM D1556-90).

One test section, the control section, was unreinforced. In the other three sections, a geosynthetic was placed, without pretensioning, at the subgrade-base course interface. The three types of reinforcement were Geotextile A, Geotextile B, and the geogrid.

Following subgrade construction and geosynthetic placement, the base course aggregate stockpile was brought to a water content within 1 percent of the optimum value of 6.3 percent. Using procedures similar to those used for the subgrade material, the aggregate was placed and compacted to at least 95 percent of the maximum dry density as determined by ASTM D1557-90. It was found that a loose lift 18 cm thick would compact to a compacted base course layer 15 cm thick. Again the water content and dry density were verified using sand cone tests. Layer thicknesses at different locations were verified by surveying.

Approximately 1.5 tons of HMA were used as a wearing surface on each test section. After delivery by a local contractor the HMA was placed using a front-end loader and hand tools. The HMA was compacted to a density of 2.16 g/cm^3 on the basis of the results of a Troxler Model 3440 nuclear density gauge and core verification. After compacting the HMA to a nominal thickness of approximately 7 cm, the pavement section was surveyed.

Loading and Instrumentation Systems

The pavement loading system was developed through the use of pneumatics and computer control. To simulate traffic loads a force of approximately 40 kN was applied to the pavement surface through a steel plate 30 cm in diameter (550 kPa pressure) at a cyclic rate of 0.5 Hz. The magnitude of the applied load was monitored and recorded through the use of a load cell. Deformation of the pavement surface was monitored and recorded through an array of linear variable displacement transformers (LVDTs).

The loading system used a Bellofram air cylinder to transfer a force, via a lever system, directly to a loading plate 30 cm in diameter placed at the center of the test section surface. The pressure applied to the Bellofram air cylinder was controlled by a Schrader Bellows PAR-15 digital pressure regulator operated by a personal computer with parallel printer interface. With this system virtually any loading pattern could be achieved, limited only by the speed at which air could enter and exit the air cylinder.

The instrumentation system consisted of eight LVDTs and one load cell, as illustrated in Figure 3. The LVDTs were mounted at 15-cm intervals along the longitudinal axis of the test pit and were secured by a frame that was isolated from the motions of the reaction frame and loading system, except for the two LVDTs on the two loading plates, which were mounted 2.5 cm from the edge of the plate. The LVDTs were used to measure pavement surface displacement and the load cell was used to monitor the loads applied by the air piston. The data acquisition system consisted of analog-to-digital converters and multiplexing cards that measured the resulting voltages, converted them to binary format, and stored them in a data file. Measurements were collected five times per second.

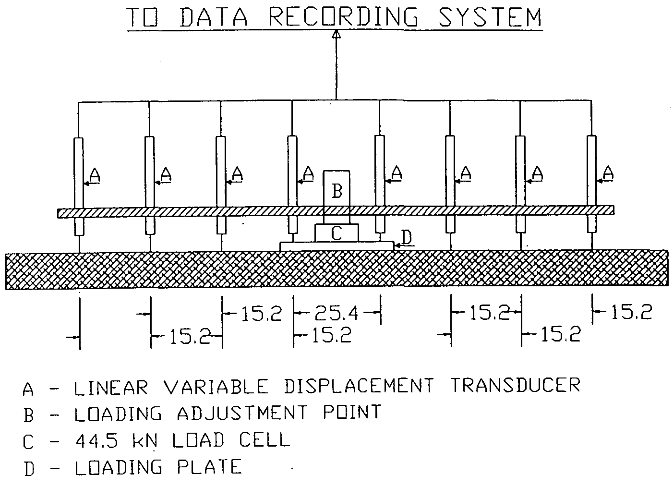

FIGURE 3 Schematic of instrumentation system.

PAVEMENT TESTING PROCESS

After paving a test section at least 24 hr were allowed to pass before loading commenced. During this period the loading system was installed. The cyclic loading was applied in 200-cycle increments, necessary because the loading pins connecting the Bellofram air cylinder and the load cell with the lever arm required adjustment after the pavement surface deflected. This loading process was continued until at least 25 mm of displacement had occurred at the pavement surface beneath the loading plate.

After the loading process the test pit was carefully excavated. The pavement was cut along the centerline and the materials were excavated from the front half of the pit, in layers approximately 15 cm thick, to a depth of 0.6 m. The condition of the final wearing surface, base course aggregate, and the subgrade were inspected, and the thicknesses and displacement profile were measured across the pavement section. Displacement of each layer at the center of the section was measured and is reported in Table 4. As each soil lift was excavated the water content of the lift was checked to verify that no downward seepage had occurred during the period between test section construction and completion of loading.

RESULTS AND ANALYSIS

Performance of the test sections was evaluated by studying the following relationships:

- Effect of loading cycles on displacement,
- Displacement profile at 800 cycles, and
- Displacement progress.

Visual observations and measurements of the excavated profiles were also useful in the evaluation.

TABLE 4 Thickness and Displacement of Each Layer of Evaluated Sections

Reinforcement Type	AVG Applied Press./cycle (KPa)	Subgrade CBR (%)	HMA Thickness (cm)	Base Thickness (cm)	Displace* in HMA (cm)	Displace* in Base Layer (cm)	Displace* in Subgrade (cm)
None	543	4.4	7.6	14.8	0.4	1.2	1.3
Geogrid	525	5.7	7.3	14.5	0.8	0.3	1.3
Geotextile A	525	4.5	7.2	13.4	0.3	0.4	1.9
Geotextile B	550	4.2	7.1	14.6	1.0	0.4	1.2

* Displacement taken at failure, see Table 6.

Effect of Loading Cycles on Displacement

A typical relationship between displacement and loading cycles is presented in Figure 4, showing that displacement increased with the increasing number of cycles, while the rate of displacement decreased. Initial large displacement after the end of the first 25 cycles can be attributed to load seating. A significant displacement was recorded in the first 200 cycles in each test section. At the end of each loading sequence, the pavement continued to rebound, and it was found that this may have continued for as long as 5 min. The rebound was recovered in the first 5 to 20 cycles of the next loading series.

Displacement Profile at 800 Cycles

The instrumentation scheme used for the test sections allowed profiles to be developed of permanent displacement for a given number of cycles, which is particularly valuable in comparing the reinforced sections with the unreinforced control section. Figure 5 shows the profiles of displacement at 800 cycles. Table 5 shows displacements and relative performance illustrated by this graph.

Displacement of the pavement section occurs up to a considerable distance away from the loading plate. This effect was verified by inspection of the cross-sections excavated after loading. Visual inspection indicated that the rutting that occurred in the different layers of the test sections was mostly consolidation rutting. The flow-type rutting observed by Webster (*9*) was minimal in this study. It is also apparent from Figure 5 that a small amount of tilt occurred in the loading plate by 800 cycles. This can be attributed to local variations in the density of the HMA, the base course, or the subgrade.

Displacement Progress

The performance of the test sections was compared by studying displacement beneath the center of the loading plate as a function of the applied number of cycles. This relationship is shown in Figures 6 and 7. Figure 6 plots the test data as measured; in Figure 7, the results are adjusted to account for load seating, which is considered to have occurred in the first 25 cycles.

The figures show that the geogrid and geotextiles all performed comparably, particularly as the number of cycles increased. It also appears that they substantially improved the pavement's resistance to displacement. It can be seen that the reinforcement had an almost immediate effect. For example the control section required only about 25 cycles for the first 12.5 mm of displacement, whereas the reinforced sections required approximately 200 cycles.

The improvement in performance of the reinforced sections can be quantified by comparing either the displacements measured at the loading plate for a given number of cycles or the number of cycles required to produce a given displacement. Table 6 gives the number of cycles required to obtain 25 mm of displacement and the performance of the reinforced sections relative to the control, with and without the effect of load seating.

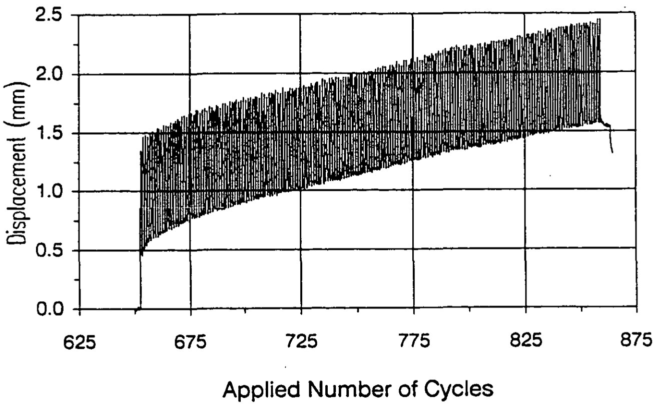

FIGURE 4 Typical relationship between displacement and loading cycles.

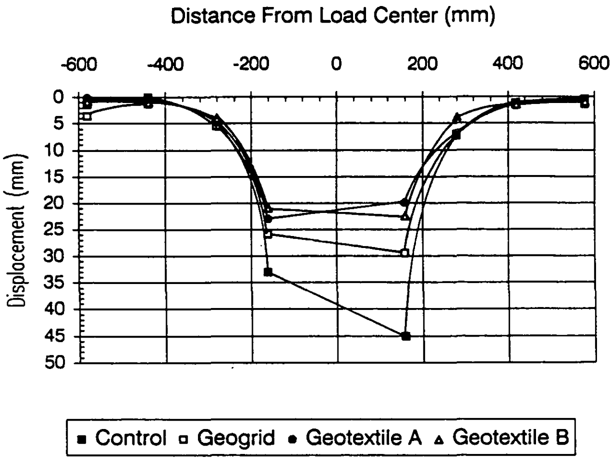

FIGURE 5 Permanent displacement profile at 800 cycles.

TABLE 5 Displacement Profile of Pavement Sections at 800 Cycles

Type of Reinforcement	Displacement (mm)		Improvement Over Control Section (%)	
	Before Load Seating	After Load Seating	Before Load Seating	After Load Seating
Control	38.9	25.7	-----	----
Geogrid	27.2	25.8	43.0	0.4
Geotextile A	21.5	19.9	80.9	29.1
Geotextile B	20.8	19.0	87.0	35.3

Observation of Excavated Sections

In an attempt to discern the amount of displacement that occurred in the wearing surface, the base course, and the subgrade, measurements were made of the final thicknesses of each of these components during the excavation process. The measurements indicate that most of the total displacement occurred in the subgrade. Table 4 shows the displacement in each layer of the evaluated sections.

An interesting observation was also made regarding the base course–subgrade interface in the excavated profiles. In the control and geogrid-reinforced sections the granite aggregate material had penetrated into the silty sand subgrade material and the silty sand had migrated in between the granite aggregate particles. It was obvious that the geotextiles were effective in preventing fines migration between the base course and subgrade layers. This observation was in agreement with the field study conducted by Austin and Coleman (*10*). It appears that the separation mechanism is more important in strengthening reinforced pavement sections than has been reported previously in the literature. This observation is supported by the results of the Falling Weight Deflectometer tests conducted by Barksdale et al. (*6*) and Webster (*9*), which did not show any significant difference between reinforced and unreinforced pavement sections.

CONCLUSIONS

The benefits provided by geosynthetic reinforcement of pavement sections constructed over weak subgrades must be understood and quantified if an adequate cost comparison is to be made. Until now the decision to use a given type of reinforcement has been largely based on field experience and empirical design methods, a nonmechanistic approach. This practice may result in unnecessary expenditures on geosynthetic materials that either are not required or are entirely inadequate.

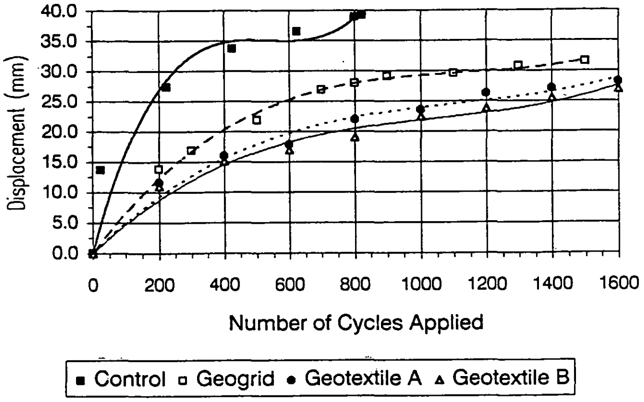

FIGURE 6 Progressive displacement for control and reinforced sections.

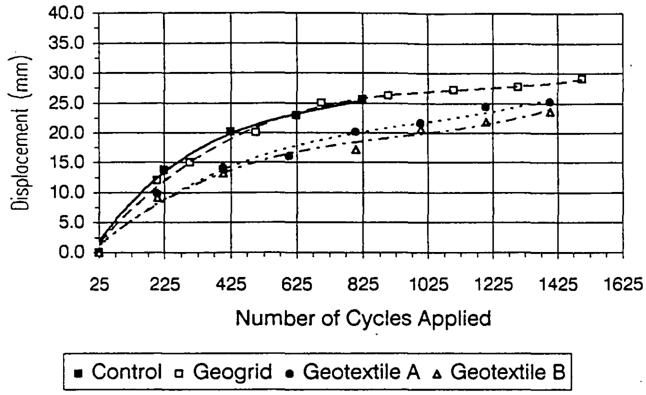

FIGURE 7 Progressive displacement for control and reinforced sections after load seating.

The results of this ongoing research are preliminary in nature because they are effectively based on the results of four test sections; the data yielded by these sections will be further analyzed and other pavement sections will be investigated. In addition the results were collected using a small-scale pavement mode that was subjected to an accelerated loading process without having been subjected to some of the environmental factors that influence full-scale pavement section performance. Based on the testing and analysis performed thus far, the following conclusions can be stated:

1. Geotextiles and geogrids can offer substantial improvement to the performance of a pavement section constructed on a low-CBR subgrade.
2. It appears that the reinforcing mechanisms of geotextiles and geogrids are different. Geotextiles can provide substantial separation between the subgrade and the aggregate layers. This mechanism appears to be more important in improving pavement structural capacity than has been reported previously in the literature.

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TABLE 6 Number of Cycles Required To Obtain 25 mm of Displacement

Type of Reinforcement	Number of Cycles		Improvement Over Control Section (%)	
	Before Load Seating	After Load Seating	Before Load Seating	After Load Seating
Control	180	710	----	----
Geogrid	625	725	247	2
Geotextile A	1150	1420	539	100
Geotextile B	1285	1540	614	117

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