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research report

Benefits of Using Geotextile Between Subgrade Soil and Base Course Aggregate in Low-Volume Roads in Virginia

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<p>Abstract:</p> <p>Geosynthetics have increasingly been used since the 1960s in pavement structures to provide reinforcement; to serve as a permeable separator to prevent mixing of subgrade with subbase or base course materials; and to provide drainage. A reliable method of quantifying these benefits is needed to justify the more widespread use of these materials.</p> <p>The purpose of this study was to quantify the benefit of using a geotextile as a separator in low-volume roadways such as secondary and subdivision streets. A field trial was conducted on a section of Virginia Route 743 near the Charlottesville-Albemarle Airport in Albemarle County to achieve this objective. A geotextile was placed between the aggregate base and subgrade in one lane of the section to prevent failure attributable to intermixing, and the adjacent lane was left unmodified as a control. In addition to the field trial, a small-scale accelerated loading laboratory test was conducted to quantify the benefit of using geotextile as a separator for a range of pavement design variables, including variations in soil strength, traffic volume, and aggregate properties.</p> <p>A statistical analysis of data gathered by a falling weight deflectometer during construction and after 8 months of traffic showed the lane with geotextile to have a slightly higher structural capacity. As severe intermixing and base failure in the control section were not expected during the 8-month period because of the low volume of traffic and a dry season, the benefit may have been attributable to a reinforcing effect.</p> <p>Although the size of the apparatus and the boundary condition may have prevented the most accurate quantification of the benefit, the laboratory testing further demonstrated the benefit. Most laboratory samples with geotextile had less deformation than the control sample. Intermixing of soil and aggregate was not observed when very densely graded base aggregate was used. When a more open-graded aggregate was used, the geotextile reduced the amount of fines migration into the aggregate layer; however, the fouled aggregate did not appear to have lost significant structural stiffness. Therefore, the separator benefit of geotextile in the laboratory testing was also apparently attributable to a reinforcing effect.</p> <p>The use of geotextile materials appears to have great potential to extend the service life of pavements on the secondary road system, offering significant cost savings to VDOT. It is recommended that this section of road be periodically evaluated to quantify this potential increased service and that more test sections on subdivision streets with a weaker subgrade condition or full-scale accelerated testing be conducted for a reliable quantification of the benefit.</p>				

FINAL REPORT

**BENEFITS OF USING GEOTEXTILE BETWEEN SUBGRADE SOIL AND BASE
COURSE AGGREGATE IN LOW-VOLUME ROADS IN VIRGINIA**

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ABSTRACT

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FINAL REPORT

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INTRODUCTION

Virginia has one of the largest road networks in the nation, with more than 124,000 lane-miles of pavement. Of that, approximately 97,000 lane-miles are classified as secondary routes. These include most subdivision, local, and farm-to-market roads, which often have very thin pavement structures, low design reliabilities, and limited budgets to construct and maintain. The Virginia Department of Transportation (VDOT) assumes a large degree of risk in its acceptance policy for subdivision roads and must deal with unforeseen soil conditions, increased traffic demand, and any other factors that may cause premature failure of the pavement.

Geosynthetics have been increasingly used since the 1960s to increase the performance, reliability, and service life of roadways. They can reinforce pavement foundations, provide separation between structural layers, prevent fouling of aggregate materials by filtering deleterious materials, promote and aid drainage, and prevent moisture intrusion. Of the various types of geosynthetics, geotextiles are the most appealing for use in secondary and subdivision roads to improve or protect the pavement structure. They offer a low-cost alternative to chemical stabilization, select removal and replacement, and aggregate working platform stabilization of weak subgrade soils; throughout the life of the pavement, they can continue to prevent intermixing of the soil and aggregate, increase structural capacity through reinforcement, and maintain drainage performance. From a simple cost perspective, the material and installation costs of common geotextiles at approximately \$6,000/lane-mile comprise a much less expensive alternative to interim rehabilitation and repair costs at \$40,000/lane-mile or more for an equivalent total service life.¹

VDOT currently uses geotextiles and other geosynthetics. Despite their proven benefit from a qualitative perspective, a reliable method of quantifying their benefit is needed to justify their more widespread use.

PURPOSE AND SCOPE

The purpose of this study was to gather data to quantify the benefit of the use of geotextiles on secondary routes. A small-scale study in the laboratory was performed to try to

develop a simple method for rapidly assessing the possible benefit under a wide range of conditions. A field study is also underway to provide calibration of laboratory results and experience under full-scale, real-world conditions. The field study is configured so as not to accelerate pavement deterioration intentionally or otherwise attempt to modify the structure of the subject pavements.

The scope of the study was limited to the use of geotextile in a low-volume roadway as part of a realignment of Virginia Route 743 near the Charlottesville-Albemarle Airport in Albemarle County, Virginia.

METHODS

Three tasks were performed to achieve the study objectives:

1. The literature was reviewed to determine the state of the practice regarding the use of geosynthetics in pavement foundation.
2. A field trial section was constructed with geotextile incorporated between the subgrade and the base layers and was monitored for performance improvement.
3. A small-scale accelerated loading laboratory test was conducted to quantify the benefit of using geosynthetics for a variety of pavement structures.

Literature Review

The literature regarding the use of geosynthetics in pavement foundation design and analysis was identified using the resources of the VDOT Research Library and the University of Virginia library. Online databases searched included the Transportation Research Information System, the Engineering Index (EI Compendix), Transport, and WorldCat, among others. Information was also gathered from standards for soils classification and testing from the American Society of Testing and Materials (ASTM) and materials specifications from the American Association of State Highway and Transportation Officials (AASHTO).

Construction of Field Trial Section and Evaluation of Geotextile Performance

As part of a realignment of Virginia Route 743 near the Charlottesville-Albemarle Airport in Albemarle County, Virginia, an area was identified as having soil conditions and a pavement structure that might be susceptible to developing pavement performance problems that geotextiles could prevent: fine-grained soil with low values for the California bearing ratio (CBR) and a relatively thin pavement structure. The relative location is shown in Figure 1.

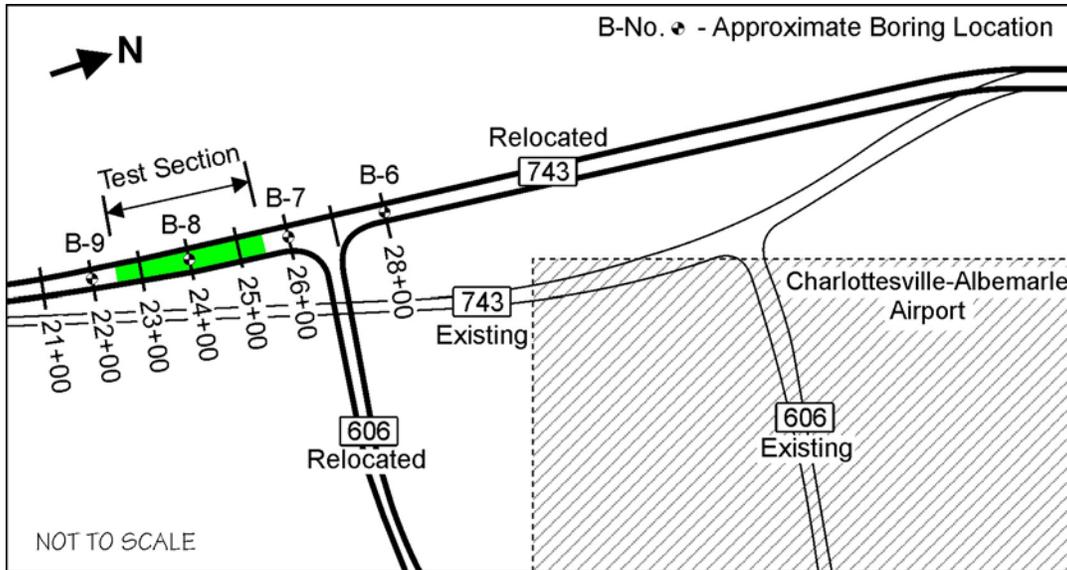


Figure 1. Map Showing Test Section Between Points B-7 and B-9

The design pavement section consisted of a 1.5-in layer of VDOT SM-9.5A hot-mix asphalt (HMA) (9.5 mm nominal maximum aggregate size, PG 64-22 binder); a 6.5-in layer of VDOT BM-25.0 HMA (25 mm nominal maximum aggregate size, PG 64-22 binder); and 12 in of VDOT 21-B graded aggregate base. No modifications of the section were made for the geotextile test lane. Pavement design parameters are listed in Table 1, and cross sections are depicted in Figure 2.

As the subgrade was prepared, bulk samples were taken for laboratory analysis and non-destructive tests were performed in each lane to determine the subgrade condition along the length of the section. A geotextile was selected in accordance with VDOT specifications³ and AASHTO M288⁴ and installed in the northbound lane. The southbound lane was constructed without a geotextile to serve as a control section. The geotextile installation was simple and included the following steps:

Table 1. Pavement Design and Evaluation Input Parameters for Field Test Section

Parameter	Value
Total design structural number	4.22
Performance period	20 years
Average daily traffic	9,600
Percent trucks	6%
Truck factor	1.28
Truck volume growth rate	2.5%
Design equivalent single-axle loads	3,439,480
Initial serviceability	4.2
Terminal serviceability	2.8
Design roadbed resilient modulus	7,500 psi
Reliability	81%
Overall standard deviation	0.49

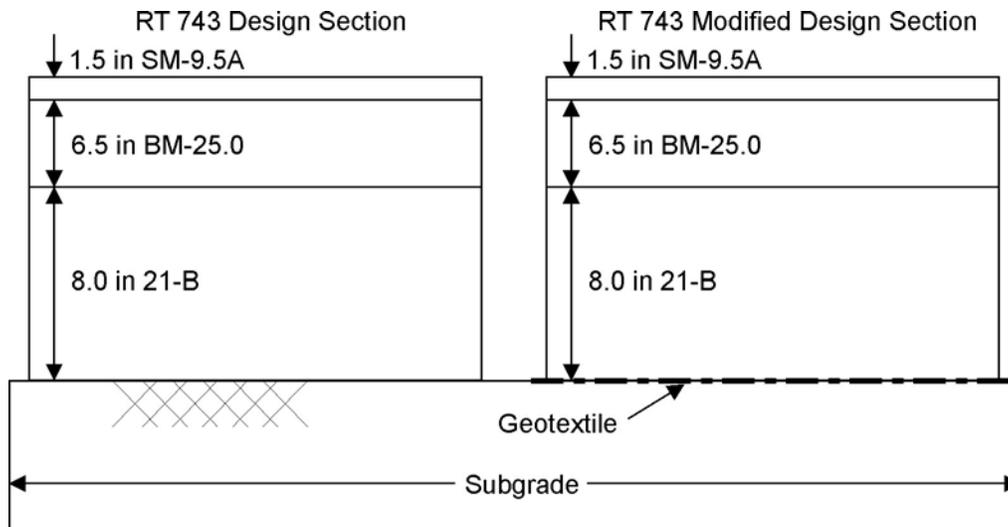


Figure 2. Pavement Design Sections for Control and Test Lanes

1. Prepare subgrade according to standard procedures.
2. Unroll geotextile on test lane.
3. As geotextile is unrolled, broadcast pea gravel or base aggregate over geotextile to secure placement.
4. Prevent construction traffic from driving directly on placed geotextile.
5. To protect geotextile, back dump base aggregate from transport trucks and spread with a tracked bulldozer to a lift thickness not less than 6 in.
6. Compact aggregate in accordance with standard procedures.

Materials Characterization

The preliminary site investigation² revealed that the surface soils along the site consisted of low plasticity, sandy lean clay (CL) and sandy elastic silt (MH). Proctor density and CBR test results for soil obtained from around Station 24+00 of the test section indicated a maximum dry density of 85.1 lb/ft³ at 36.5 percent moisture content and a corrected soaked CBR value of 3.7 percent. Soils beyond about 27+00 had a high mica content and were not tested in this study.

Additional random, bulk subgrade samples were collected within the test section at Stations 21+00, 22+00, and 24+00. The soil samples were analyzed in accordance with the following laboratory tests⁵:

- ASTM D 2487, Standard Test Method for Classification of Soils for Engineering Purposes
- ASTM D 422, Standard Test Method for Particle-Size Analysis of Soils

- ASTM D 1140, Standard Test Method for Amount of Material in Soils Finer Than the No. 200 (75- μm) Sieve
- ASTM D 4318, Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- ASTM D 698, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³[600 kN-m/m³])
- ASTM D 1883, Standard Test Method for CBR of Laboratory-Compacted Soils.

The sample obtained from Station 24+00 had a gradation of 91.7 percent passing the No. 200 sieve and liquid and plastic limits of 69 and 48 percent, respectively. The soil was classified as an elastic silt (MH). The moisture-density tests determined the soil to have a maximum dry density of 80.5 lb/ft³ at an optimum moisture content of 37 percent. The soil had an unsoaked CBR of approximately 10 percent and a soaked CBR of 4.5 percent.

The samples from Stations 21+00 and 22+00 were classified as sandy clay (CL) or sandy silt (ML); the sample from Station 22+00 had a maximum dry density greater than 97 lb/ft³ and an optimum moisture content less than 17 percent. This soil was distinctly different than the soil obtained from around Station 24+00, as mentioned previously.

From this analysis, the middle of the site was found to have an area of weak soil surrounded by much stronger materials. The pavement design was based on a CBR of 5 percent.² In the areas of localized weaker soil, where the pavement section may be under-designed, a geotextile separator may help protect the subgrade, maintain the pavement structure, and reduce the possibility of premature failure and the need for costly repair.

As the base course aggregate was being placed, a bulk sample was obtained and brought back to the laboratory for analysis. Two tests were performed on the sample to verify the properties supplied by the manufacturer:

- ASTM C 566, Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying
- ASTM C 136, Sieve Analysis of Fine and Coarse Aggregates.

The aggregate sample had a moisture content of 5.1 percent, within 2 percent of the manufacturer's reported optimum moisture content of 5 percent. The gradation complied with VDOT specifications.³

The geotextile properties as reported by the supplier are provided in Table 2. The geotextile was placed in the test (north) lane for 300 ft starting from Station 22+50 to Station 25+50 with the direction of the machine aligned parallel to the direction of traffic.

Table 2. Properties of Geotextile

Property	ASTM Test Method Designation	Minimum Average Roll Value
Type	-	Woven
Polymer	-	Polypropylene
Cost per unit area	-	0.66 per yd ²
Mass per unit area	-	7.57 oz/yd ²
Grab tensile strength ^a	D 4632	315 lb (Class 1)
Grab tensile elongation ^a	D 4632	15%
Puncture strength	D 4833	125 lb
Mull burst strength	D 3786	650 psi
Trapezoidal tear strength	D 4533	120 lb
Apparent opening size	D 4751	No. 70 sieve (maximum)
Permittivity	D 4491	0.07 sec ⁻¹
Flow rate	D 4491	5.0 gpm/ft ²

^aValues apply to both machine and cross-machine directions of geotextile.

Testing Devices

Dynamic Cone Penetrometer

The dynamic cone penetrometer (DCP) is a portable device that measures the shear strength and penetration resistance of soil, aggregate, and asphalt layers. The DCP used in this study used a 17.6-lb (8-kg) mass and a drop height of 22.6 in (575 mm). A 0.79-in (20-mm) diameter, 60-degree conical tip is driven dynamically into and through the test material by the action of the drop weight. A 0.63-in (16-mm) diameter rod transfers the drop energy to the tip; the smaller diameter of the drive rod reduces the possible influence of shaft friction. The penetration depth from each drop is recorded.

After the penetration depths for each blow are measured, the DCP penetration index (DCPI) or DCP penetration rate (PR) in millimeters per blow may be computed. PR for a given layer is usually constant, and because of this, the DCP can also determine layer boundaries and thicknesses. The DCP PR can also be correlated to the CBR using Eq. 1 or Eq. 2.⁶

$$CBR = 292PR^{-1.12} \quad \text{For } CBR > 10\% \quad \dots \dots \dots \text{ (Eq. 1)}$$

$$CBR = \frac{1}{(0.017019 * PR)^2} \quad \text{For } CBR < 10\% \quad \dots \dots \dots \text{ (Eq. 2)}$$

where

CBR = California bearing ratio (%)
 PR = DCP penetration rate (mm/blow).

Since CBR is a widely used and familiar parameter in the pavement design community, the correlation was used to convert PR to CBR for presentation and analysis.

Falling Weight Deflectometer

The falling weight deflectometer (FWD) is a standard device for testing the response (deflection) of pavement layers to a dynamic load. A series of velocity transducers (geophones) record the peak surface deflections of the pavement structure in response to a pulse load supplied by a falling mass and transferred to the pavement by a steel load plate with a radius of 5.91 in. Four standard load levels (6, 9, 12, and 16 kips) were used to apply the dynamic load, and deflections were measured at 0, 8, 12, 18, 24, 36, 48, 60, and 72 in from the center of the load plate. FWD deflection data were collected at 30-ft intervals in each lane of the test section on two occasions:

1. *Month 0 (July 16, 2007)*: after construction of the first 3 in of HMA binder layer
2. *Month 8 (April 17, 2008)*: 8 months after opening to traffic on the full-depth structure.

The resulting data were analyzed with VDOT's FWD analysis program MODTAG.⁷ To compare the two sections, at each test point, the effective structural number (SN) and effective subgrade resilient modulus of the pavement were computed. The apparent subgrade resilient modulus for each point was computed from the deflection readings of the outer sensors so that only the influence of the subgrade is measured. The effective SN was computed based on the effective resilient modulus and center sensor deflection; by removing the amount of deflection attributable to the underlying subgrade on the center sensor deflection measurement, the performance of the structural pavement layers is isolated for analysis. The viscoelastic, temperature-dependent behavior of asphalt materials is considered in the analysis of deflection data. The subgrade strength is also strongly influenced by climactic factors. Climactic data were recorded during testing and can be inferred from weather station data archives from the nearby Charlottesville-Albemarle Airport.

Pairwise Statistical Comparison

In addition to the numerical comparison of the average values for control and geotextile sections, a pairwise statistical comparison was performed. A paired *t*-test was used to compare the test from each lane. This analysis assumed that the lateral variability across lanes would be less than the total variability along the entire section length. Thus for each station where two or more measurements were taken along the lateral dimension, the difference between each pair of values was computed. The mean and standard deviation of all difference pairs along the test site were then computed. These statistics were then compared with a one-tailed *t*-test for differences greater than zero, implying that one set of measurements is statistically greater than the other. A *p*-value reports the minimum level of significance for which the null hypothesis (that one is not greater than the other) may be rejected. For this study, a comparison was determined to be significant at a *p*-value less than 5 percent.

Laboratory Evaluation of Benefit of Geotextile for Variety of Pavement Structures

A laboratory testing plan was developed that would allow for a direct evaluation of the benefit of geotextile separators for a variety of pavement structures. The testing matrix was not intended to allow a comprehensive evaluation of the influence of each variant; instead, a more applied, practical rationale was implemented to assess the benefit (usually in terms of an extension of service life) as would be currently realized without modification of current pavement design procedures or reduced layer thicknesses.

In accordance with VDOT's *Pavement Design Guide for Subdivision and Secondary Roads in Virginia*,⁸ the required pavement structure for a given service life, traffic volume, and subgrade strength was computed. Multilayer elastic analysis was performed to predict the stresses that would develop on the surface of the subgrade attributable to a standard 18-kip dual-tire single axle. These stresses were then dynamically applied to a layered sample of 4 in of soil beneath 2 in of aggregate compacted into a CBR mold. Samples were constructed and tested in the rigid molds to limit overall lateral deformation.

Characterization of Test Materials

Subgrade Soil

The soil for this study was a low plasticity sandy silt (A-5, ML). Approximately 60 percent by mass of the material passed the No. 200 sieve. The plastic limit of the soil was 42 percent with a plasticity index of 2 percent. The soil had a maximum dry density of 100 lb/ft³ at an optimum moisture content of 23 percent. At optimum moisture, the soil had a soaked CBR of 9 percent. In addition to the standard CBR test, a range of CBR tests was performed at varying molding moisture contents (compacted to 100 percent of the corresponding dry densities determined by the standard Proctor test results) to allow for a range of soil conditions to be modeled. The results of this testing are shown in Figure 3.

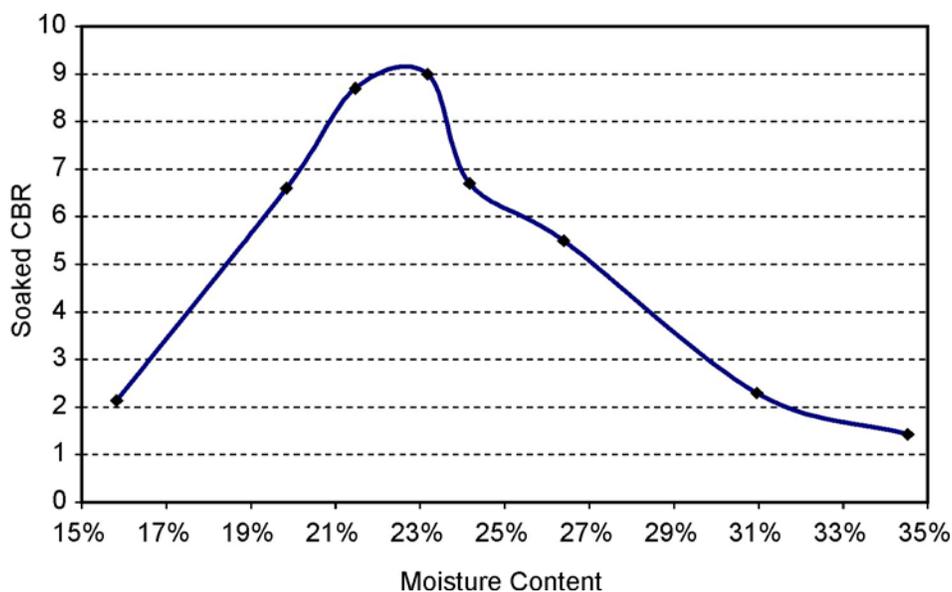


Figure 3. Soaked CBR Versus Molding Moisture Content. CBR = California bearing ratio.

Aggregate Base

VDOT 21-B aggregate was obtained from a local supplier. The grain size distribution of the aggregate, shown in Figure 4, indicated that it was somewhat finer than the allowable VDOT gradation specifications.³ The aggregate had a maximum dry density of 148 lb/ft³ at an optimum moisture content of 5 percent in accordance with AASHTO T-180, modified Proctor test.

A modified gradation of base aggregate was also used in the testing scheme. The gradation was modified to create a coarser, more openly graded distribution of particles that followed the coarser limit for 21-B aggregate with all materials passing the No. 200 and retained on the 1-in sieves removed.

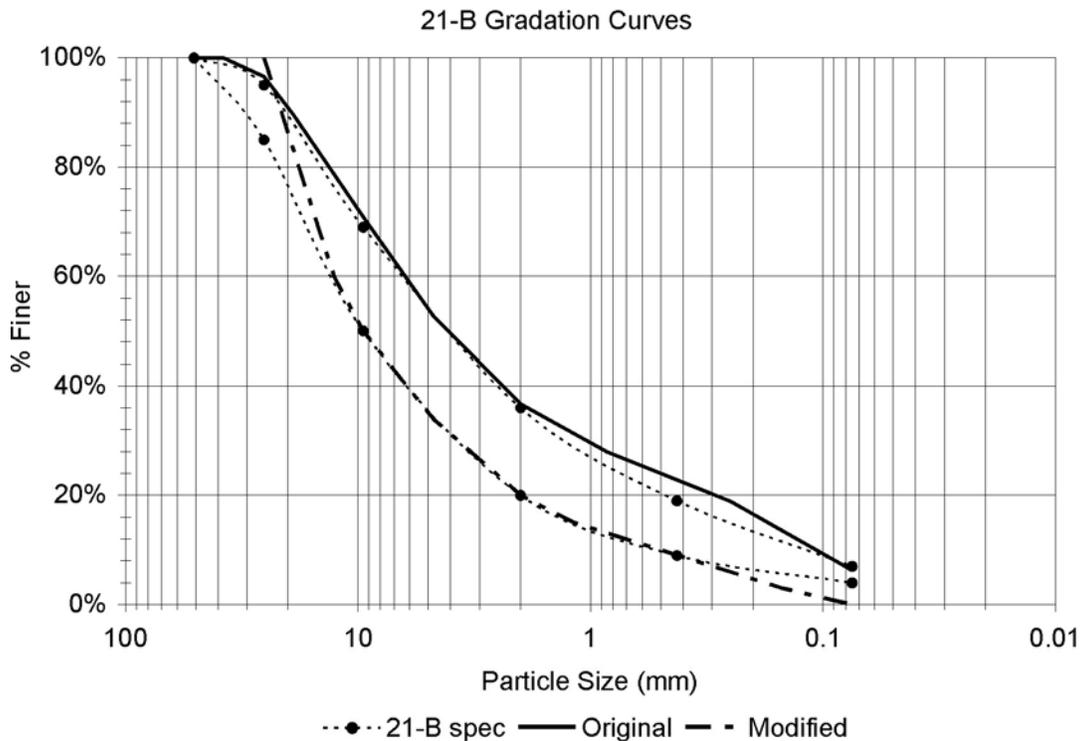


Figure 4. Original and Modified Aggregate Gradations

Geotextile

The same geotextile, a standard 315-lb tensile strength fabric, as used in the field trial section was also used in the laboratory testing. As mentioned earlier, it was selected based on meeting all current VDOT geotextile use criteria.³

Testing Procedure

Laboratory tests were performed using a servo-hydraulic testing device to place loads on specimens in standard cylindrical CBR molds (6-in diameter by 7-in height). Samples were compacted to a fixed density determined by the standard Proctor test for a target-soaked CBR value based on Figure 3. The soil for testing was compacted in two 2-in lifts using a standard

Proctor compaction hammer for a total soil thickness of 4 in. The aggregate layer was compacted to 95 percent of maximum dry density at the optimum moisture content of 5 percent. The aggregate was compacted in a single 2-in lift for a total thickness of 2 in. Particles with a dimension of 1.5 in or greater were removed prior to compaction. The loose aggregate was first gently packed down by hand to prevent any excessive deformations in the soil layer during compaction of the aggregate layer. The standard Proctor compaction hammer was then used to compact the aggregate, and a steel plate 6 in in diameter was used to level the aggregate to the required 2-in thickness.

At each soil strength, two samples were constructed: a control sample with the aggregate layer placed directly on top of the subgrade soil, and a geotextile sample with a geotextile separator between the soil and aggregate. Samples were allowed to soak under water for 4 days prior to testing to allow the surface of the subgrade to become saturated and softened, a concept similar to that behind the CBR test.

Approximately 50,000 load cycles were applied to each specimen using a servo-hydraulic MTS 810 testing frame. A standard 1.95-in-diameter CBR piston was mounted to the hydraulic actuator to apply the loads to the specimen. A load cell mounted inline of the CBR piston provided feedback to control the testing machine and acquire force data for each load cycle. Samples were loaded at approximately 2 Hz for 7 hours. Each load cycle consisted of a 0.2-sec haversine load pulse to the peak cyclic load and a 0.3-sec rest period at the contact load. The 0.2-sec load pulse simulates the stress variation with time at a point on the surface of the subgrade from a passing 18-kip dual tire, single axle. This loading cycle was adapted from standard resilient modulus testing, with a reduced rest period to expedite testing. For each load application, the peak deflection, peak load, recovered deflection, and minimum load were recorded. Loads were applied as shown in Table 3. These loads were based on the soil strength and design pavement section of each sample as discussed in the following section.

The CBR piston load head was selected to allow for a non-constant stress profile to develop in the aggregate layer and on the surface of the soil. By using load head with a diameter smaller than that of the mold, the peak stress at the surface of the soil was able to match field conditions while allowing the stresses to decrease substantially at the edge of the mold; with this non-constant stress profile, the aggregate is able to spread laterally. Spreading may create larger pore spaces for the

Table 3. Testing Matrix of Applied Loads

ADT	Soil CBR	Contact Pressure, psi	Dynamic Stress, psi	Peak Cyclic Load, lb	Contact Load, lb	Surcharge, lb
650	1.75	0.846	4.63	172.5	2.5	21.4
	3	0.760	7.31	199.3	2.3	19.2
	4	0.716	9.19	213.9	2.1	18.1
	6	0.672	12.17	231.1	2.0	17.0
	9	0.608	16.32	257.8	1.8	15.4
1800	1.75	1.215	2.64	100.7	3.6	30.7
	3	1.085	4.35	120.4	3.2	27.4
	4	1.042	5.35	126.5	3.1	26.3
	9	0.868	10.10	160.9	2.6	22.0

ADT = average daily traffic, CBR = California bearing ratio.

subgrade soil to be pumped up into the aggregate layer. This may help minimize the effects of the rigid boundary and allow more realistic simulation of the intermixing conditions found in a full-scale pavement. Even though it may reduce the effect of a rigid boundary, the true field behavior of the soil and aggregate layers would not be possible.

The very small size of the test samples creates concerns about the mismatch of dimensions of the aggregate particles, mold diameter, and loading head. Although the smaller load head allows for the development of a non-constant stress profile within the bounds of the mold, it is also susceptible to influence from large aggregate particles. These proportions between the CBR piston area and aggregate particle size would not exist in a full-scale pavement. The contact area of the modeled truck tire has a nominal radius of 5.98 in, and the stress profile is distributed over a much greater lateral extent for the full-scale pavement. These are considered limitations of the study along with the rigid boundary; calibration against full-scale testing is required to determine the actual behavior.

Computation of Test Parameters

The design life was fixed for all trials at a standard value of 15 years. The samples were loaded up to 50,000 cycles for a relative comparison of control and geotextile samples. As mentioned earlier, the deviator stresses (peak cyclic load in Table 3) were selected based on the layered elastic analysis of the designed structure as to produce same stress at the base-subgrade interface. There were three rounds of testing:

1. *Round 1.* The traffic volume was selected to be an average daily traffic (ADT) of 650 vehicles with 5 percent trucks. Using a truck factor of 1.28, this equates to 113,880 equivalent single-axle loads (ESALs) for the design life. At this traffic volume, four subgrade conditions were evaluated based on varying CBR values: 1.75, 3, 4, and 9 percent.
2. *Round 2.* Pavement sections were modeled for an ADT of 1,800 vehicles with 5 percent trucks, or 315,360 ESALs, over the pavement's design life with the same CBR values as in Round 1.
3. *Round 3.* This round of testing was performed with an open-graded base material, with a gradation modified from the Rounds 1 and 2 aggregate as discussed earlier, for the design ADT of 650 vehicles with 5 percent trucks and soil CBR values of 1.75, 3, 6, and 9 percent.

For each set of design variables, two levels of traffic and four soil support values (CBRs), a control, and a sample with a geotextile separator were constructed and tested. The laboratory testing matrix is provided in Table 4.

In the current standard design procedure used by VDOT for secondary and subdivision roads, a soil support value (based on the design CBR and a resiliency factor) and a design traffic volume are used to determine the required structural thickness of the pavement.⁸ Layer materials are assigned a thickness equivalency value and configured such that the required equivalent

Table 4. Laboratory Testing Matrix

Soil CBR (%)	Design Average Daily Traffic	
	650	1800
1.75	o, x	o
3	o, x	o
4	o	o
6	x	
9	o, x	o

CBR = California bearing ratio; o = original aggregate gradation; x = modified coarser aggregate gradation; each x or o represents one control test and one test with a geotextile separator.

thickness is reached. The modified open gradation aggregate was assigned the same thickness equivalency values as the original dense gradation (VDOT 21-B).

Using a fixed resiliency factor of 2, pavement structures were determined for each combination of design variables. For the lower volume pavement design, the HMA layer was assigned a fixed thickness of 3 in. For the higher volume pavement, the HMA layer was fixed at a thickness of 4 in. The base layer had a thickness starting at 6 in, which increased as the soil strength decreased. Table 5 shows the pavement structures designed for this study to calculate (using layered elastic theory) the stresses to be applied in the laboratory evaluation.

Once an appropriate pavement design was determined for each soil strength and design traffic volume, stresses at the interface between the subgrade soil and base course aggregate were computed using multilayer elastic analysis. The load modeled using the multilayer elastic analysis was that of a standard FWD plate (5.98-in radius) with a 9-kip load. This represents the 18-kip load of a standard ESAL with a tire pressure of 80 psi.

To convert the dynamic stress produced by the 9-kip load at the pavement surface to the load required for the laboratory testing, a 2-in layer of aggregate over an infinite subgrade was modeled using multilayered elastic analysis. The area of load head used during testing (a standard CBR piston) was input into the model and the load intensity was back-calculated out of

Table 5. Pavement Structures Designed for Laboratory Evaluation

ADT	Soil CBR, %	Thickness of Material, in	
		HMA	Base
650	1.75	3	8.75
	3	3	7.75
	4	3	7.25
	9	3	6
1800	1.75	4	12
	3	4	10.5
	4	4	8
	9	4	8
650	1.75	3	8.75 ^a
	3	3	7.75 ^a
	6	3	6.75 ^a
	9	3	6 ^a

ADT = average daily traffic; CBR = California bearing ratio; HMA = hot-mix asphalt.

^a Modified gradation aggregate.

the model such that the stress on the soil surface was equivalent. Surcharge pressures were also computed based on the representative material weights of the pavement structure above the subgrade and used as static overburden with annular weights and a contact load with the CBR head.

Evaluation

The use of rigid mold made it difficult to evaluate the test results. In an ideal situation where confining pressure could have been controlled as calculated from the layered elastic models/programs, the variation in effective resilient modulus and accumulation of permanent strain/deformation with the number of load cycles applied to the specimen would be the most appropriate parameter for laboratory data evaluation. Unfortunately, the confining pressure controlled test was not manageable because of excessive lateral bulging of the specimen during loading. In addition, as the testing progressed with the rigid mold, it became apparent that the effective resilient modulus was susceptible to large errors from slight misalignments of the loading system. These slight misalignments allowed the mold to wobble with each load application; the physical displacement attributable to wobble would be recorded as additional recoverable deformation, decreasing the effective resilient modulus value. Because of this, the effective resilient modulus may not have provided a reliable comparison between specimens. As the additional rocking motion should be perfectly elastic, the permanent deformation measurements should not have been affected. But the observed deformation for these laboratory tests must be calibrated against larger scale testing before a real-world benefit may be estimated with confidence. Two parameters were considered for evaluation:

1. accumulated permanent deformation
2. intermixing and contamination of soil and aggregate from visual observation.

Each pair of samples, a control sample with the aggregate layer placed directly on the subgrade soil and a test sample with a geotextile placed on the subgrade in between the aggregate layer and soil, was then compared to each other to assess the benefit provided by the geosynthetic. After testing, each sample was carefully extruded from the testing mold to allow for the visual inspection of the soil-aggregate interface.

RESULTS AND DISCUSSION

Literature Review

Geotextiles were first used as erosion control devices as an alternative to traditional granular fill. The initial selection criteria for geotextiles in filtration applications were permeability, soil retention capacity, strength, and elastic modulus.⁹ French researchers began using geotextiles for separation and reinforcement purposes in the late 1960s.¹⁰ They installed non-woven, needle-punched fabrics in unpaved roads, railroad foundations, and soil embankments, recognizing the ability of these fabrics to prevent the mixing of dissimilar

materials and the fouling of granular layers. They also realized the ability of fabrics to dissipate pore water pressures by allowing within plane flow of water.

Bell et al.¹¹ and Glynn and Cochrane¹² found that the intermixing of softened clay subgrade and base course aggregate caused a loss of useful depth of subbase, reduced drainability, and reduced shear strength.

Thirty months into a field study, Appea⁹ found that a geotextile separator could effectively prevent the fouling of an aggregate layer and reduce rutting by approximately 50 percent. Control sections in the field were contaminated 7 cm up into in the base layer, whereas sections with a geotextile had no contamination. After 8 years, the pavement condition was again assessed and each test section was excavated.¹³ The geotextile sections still had less rutting than the unreinforced sections. The geotextile section was able to carry 1.95 times the number of loads as the control section to reach the same rutting condition, and the contribution of the geosynthetic was found to increase with increasing pavement deterioration rate.

Black and Holtz¹⁴ reported that 5 years after installation at a site with a history of poor pavement performance attributed to a soft silty-clay subgrade, a high groundwater table, and heavy logging traffic, a geotextile separator was found to have qualitatively increased the pavement performance and reduced the pavement deterioration rates. The authors concluded that the long-term performance of the geotextile separator may not be as important as its early life functions because of the increased subgrade strength and reduced compressibility associated with the observed consolidation.

Kim et al.¹⁵ evaluated the structural contribution of stabilized and reinforced aggregate working platforms and found that elastic deformations were reduced by 8 to 12 percent on thinner working platforms (0.3 m) regardless of the geosynthetic type. For thicker platforms, elastic deformations were 24 to 27 percent smaller than the control sample with a woven geotextile; other geosynthetics had no effect. In further analysis, if the working platform was considered to function as a subbase in the pavement, the layer coefficient for SN computations was increased by 50 to 70 percent. This increase in layer coefficient was found to result in an improved SN of 3 to 11 percent, with a 5 percent increase for woven geotextiles and a 3 percent increase for non-woven geotextiles.

Narejo¹⁶ found that the geotextile selection criterion in AASHTO M 288 with regard to a fabric mesh opening size less than 0.6 mm may often be inadequate; instead the apparent opening size (O_{95}) should be less than the 85th percentile soil particle diameter (D_{85}) of the soil. If fine soil particles can be mobilized into a suspension, the ratio of O_{95} to D_{85} should be less than 0.5. Using the AASHTO recommendation, he noted cases where the ratio could be in excess of 100 and the geotextile might not retain the soil particles as designed.

Lafleur et al.¹⁷ used consolidometer cells to simulate the field conditions of upward flow conditions during dynamic consolidation. The authors concluded that as the ratio of the apparent opening size of the geotextile to the 85th percentile soil particle diameter increases or the size of subbase aggregates increases, clogging potential increases.

Hoare¹⁸ found that the amount of fines passing through a geotextile increased linearly with the log of the number of applied load cycles and could be reduced by either reducing the applied stress or using a more finely graded base course aggregate.

Friedli and Anderson¹⁹ found that under dynamic loading the amount of plastic strain was decreased for soil and aggregate samples with a geotextile separator. After approximately 1,000 to 5,000 load applications, plastic strains of samples with a geotextile were found to stabilize and stop increasing; in unseparated control samples, the strain did not stop accumulating. At the end of testing, accumulated strains were 30 to 60 percent lower and the amount of fine soil migration was decreased.

Signore and Dempsey²⁰ developed a rapid index test to quantify the performance of separation layers between chemically stabilized soils and an open-graded aggregate base. A geotextile successfully minimized pumping contamination, aggregate penetration, and total deformations for tests with soils with a CBR less than 4 percent. A dense-graded filter was found to merge with the open-graded aggregate, compromising its permeability. Because of this, the geotextile was determined to have the best separation performance.

Al-Qadi et al.^{1,21} evaluated the ability of geotextiles to maintain the integrity of an aggregate base layer using dynamic loading on laboratory tank pavement sections. In control sections, a thin layer of weak, contaminated aggregate formed at the subgrade-aggregate interface. The geotextile-stabilized sections were able to sustain 1.7 to more than 3 times the number of loads than the control sections before failing based on a rutting criterion.

Floss et al.²² felt that full-scale testing was ill suited to a large quantitative analysis testing program; thus, a smaller, laboratory scale apparatus was developed. The smaller scale apparatus was intended to allow rapid comparison of geosynthetics to quantify the benefit each could provide to typical pavement structures, especially when used to simulate the significantly increased stresses on the structures from construction traffic on the unfinished pavement.

Performance of Field Test Section

Field Measurement

The DCP-correlated CBR at each station along the section is shown in Figures 5 and 6. Figure 5 shows the correlated CBR for the subgrade as tested before the aggregate layer was placed. Figure 6 shows the CBR data for the aggregate layer and subgrade after the aggregate layer was constructed. The results of the FWD testing are shown in Figures 7 through 10. Figures 7 and 8 show the effective SN and apparent subgrade resilient modulus, respectively, at the Month 0 (July 16, 2007) testing. Figures 9 and 10 show the effective SN and apparent subgrade resilient modulus, respectively, at the Month 8 (April 17, 2008) testing. It is important to note that the FWD testing at Month 0 was on the incomplete pavement structure, after only 3 in of the bound layer had been placed whereas Month 8 testing was performed on the complete pavement structure. Direct comparisons between the two should not be made.

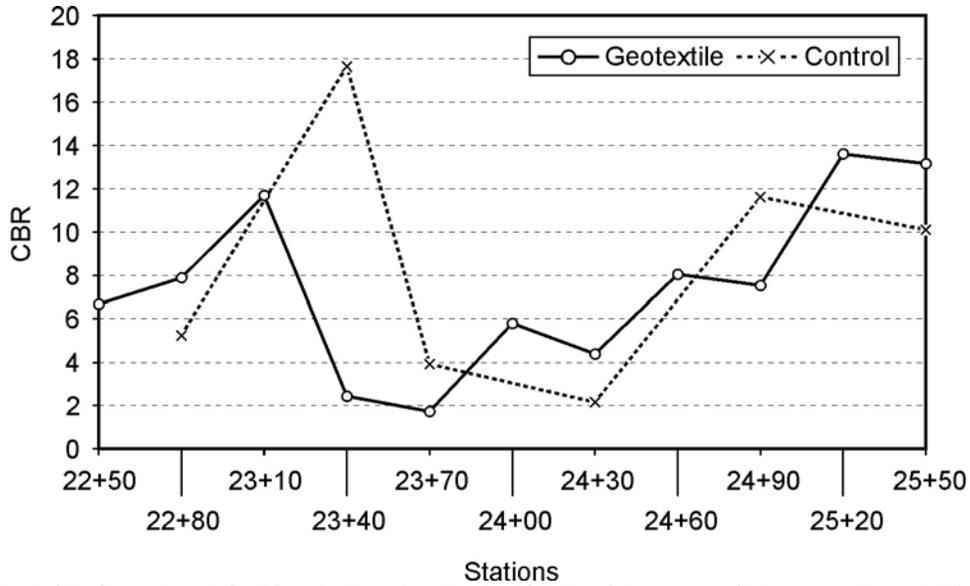


Figure 5. DCP-Correlated California Bearing Ratio (CBR) of Prepared Subgrade, Tested Directly on Subgrade Before Installation of Geotextile. Connecting lines do not represent continuous data.

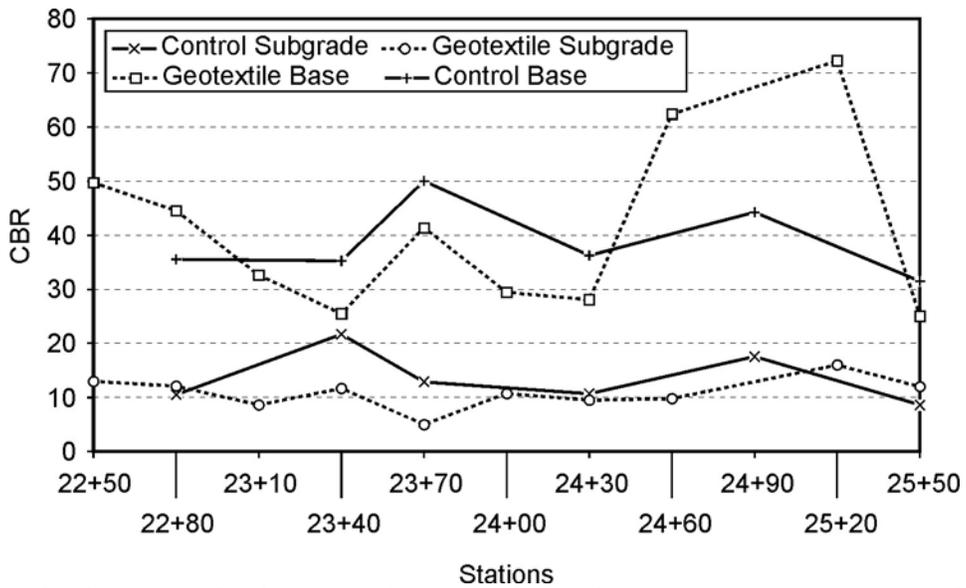


Figure 6. DCP-Correlated California Bearing Ratio (CBR) of Aggregate Base and Prepared Subgrade, Tested on Aggregate Base. Connecting lines do not represent continuous data.

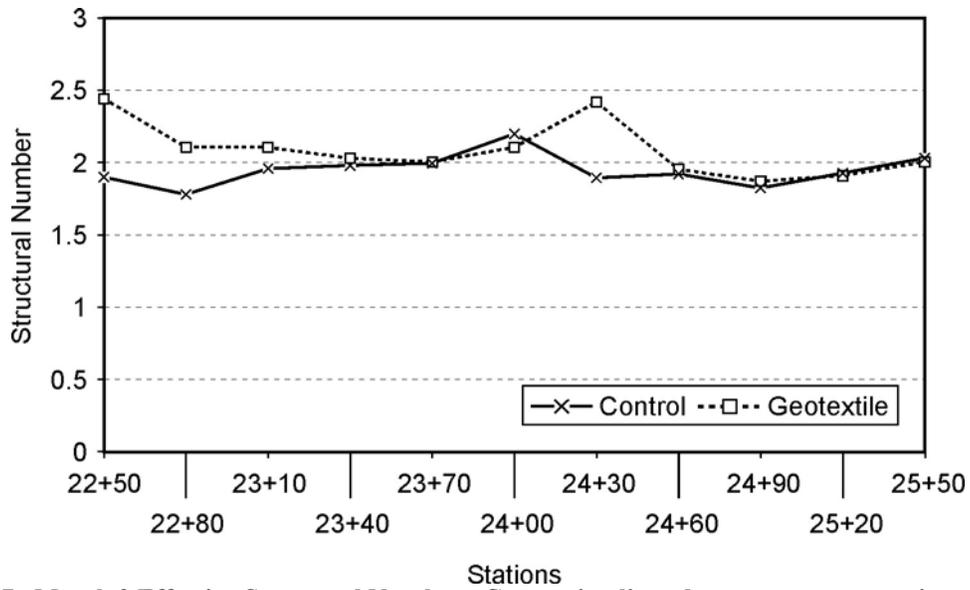


Figure 7. Month 0 Effective Structural Number. Connecting lines do not represent continuous data.

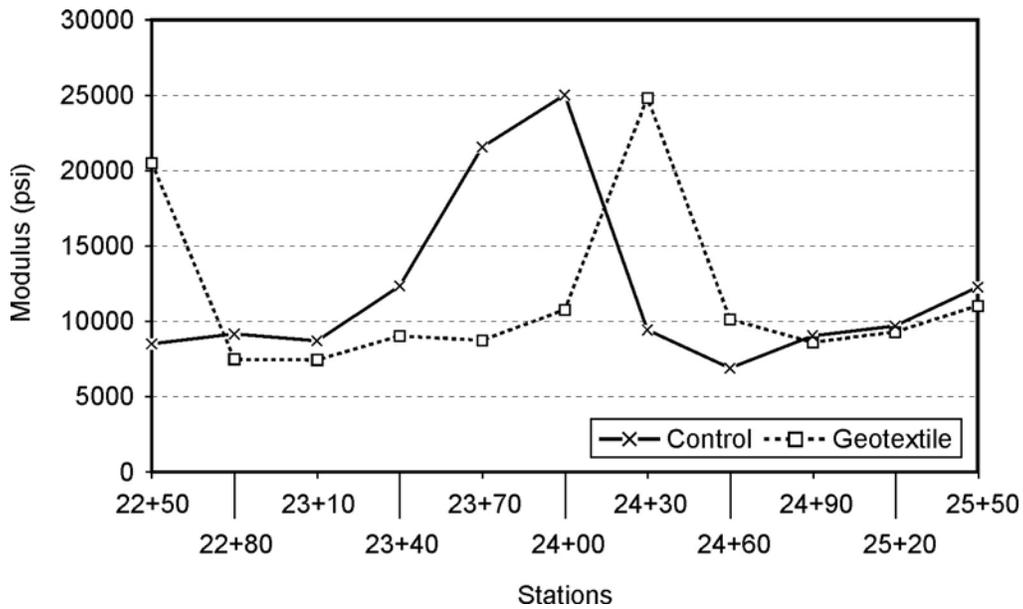


Figure 8. Month 0 Apparent Subgrade Resilient Modulus. Connecting lines do not represent continuous data.

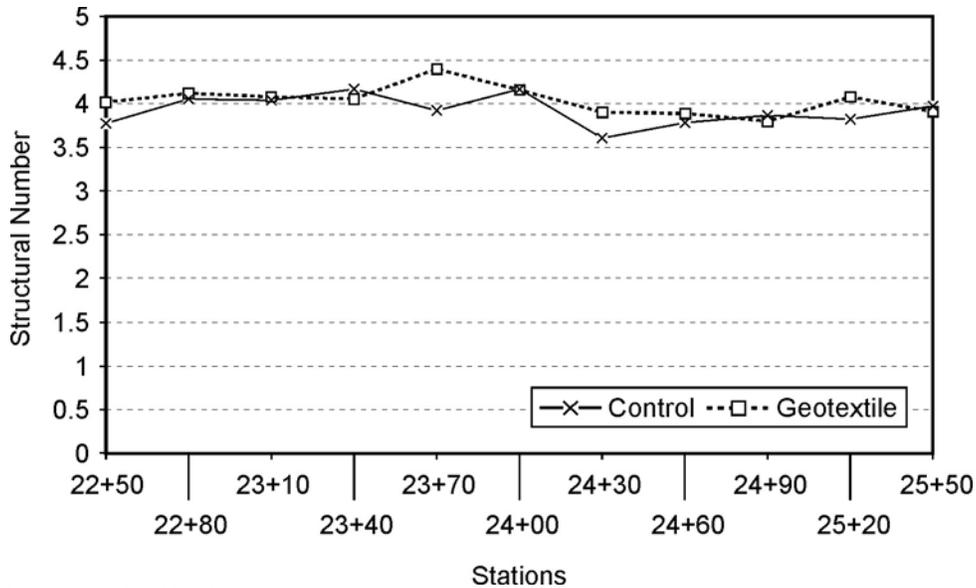


Figure 9. Month 8 Effective Structural Number. Connecting lines do not represent continuous data.

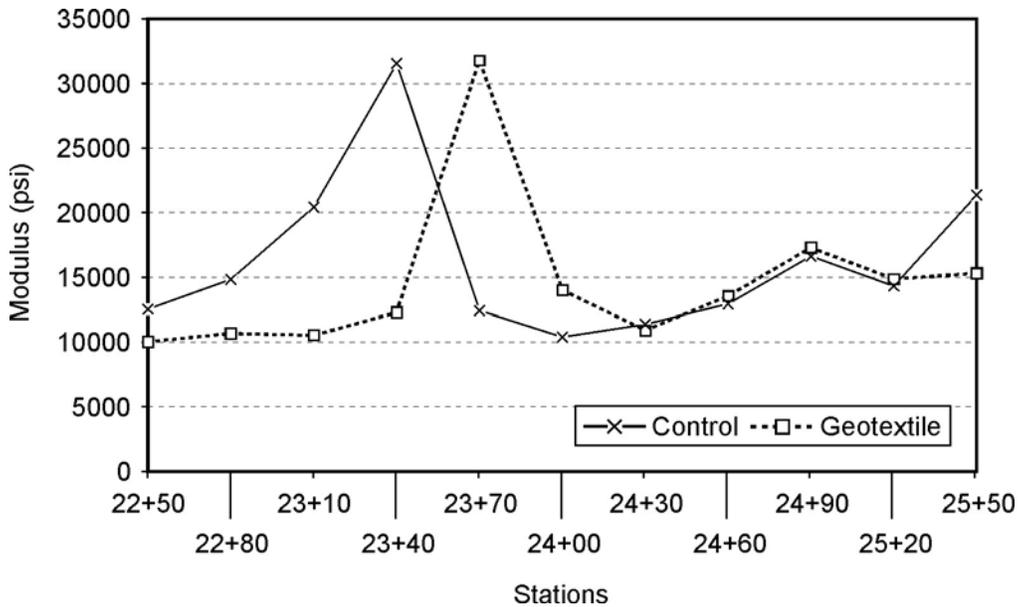


Figure 10. Month 8 apparent subgrade resilient modulus. Connecting lines do not represent continuous data.

Materials Characterization and Pavement Evaluation

Subgrade

Subgrades were evaluated using a DCP at 60-ft intervals in each test lane. The DCP test was performed directly on the prepared subgrade and the compacted aggregate base layer into the subgrade. Correlated CBR values along each lane are plotted in Figures 5 and 6. There was no obvious trend between control and geotextile sections. The paired *t*-test showed no

significant difference at a 95 percent confidence level. From the statistical analysis of the DCP data, subgrade appeared to be equivalent during both phases of testing. The apparent resilient modulus values (M_r) for subgrade from the FWD analysis from Months 0 and 8 are plotted in Figures 8 and 10. Again, there was no obvious trend, and a paired t -test showed no statistical difference between the control and geotextile sections. Table 6 summarizes the results of the statistical analysis.

Table 6. Subgrade Statistical Analysis

Measurement	N	Geotextile		Control		Significance
		μ	σ	μ	σ	
Subgrade CBR, % ^a	6	6.18	4.27	8.43	5.77	None
Base CBR, % ^b	5	32.9	9.31	37.7	7.12	None
Subgrade CBR, % ^b	5	9.14	4.21	12.42	5.69	None
FWD apparent resilient modulus, Month 0, ksi	11	11.6	5.67	12.1	5.82	None
FWD apparent resilient modulus, Month 8, ksi	11	14.5	5.87	16.1	5.90	None

FWD = falling weight deflectometer; CBR = California bearing ratio; N = sample size; μ = arithmetic mean; σ = standard deviation.

^aTested directly on subgrade.

^bTested on prepared base.

Pavement

The FWD was used to evaluate the pavement section after partial and complete construction of the bound layer (HMA). The Month 0 testing was performed after the construction of only 3 in of HMA binder course, and the Month 8 test was after 8 months of traffic on the full structure. Figures 7 and 9 show the effective SN (SN_{eff}) of the pavement for each test point. A pairwise statistical comparison showed the geotextile section to have a significantly higher SN during both rounds of testing; the results are summarized in Table 7.

Table 7 shows that the geotextile lane had and has maintained a statistically greater effective SN than that of the control, whereas the stiffnesses of the subgrade of each lane were and remain statistically equivalent, as shown in Table 6.

The increase in effective pavement SN can be used to compute an increase in pavement service life based on AASHTO 1993 design guide calculations²³ and the input parameters defined in Table 1.

Table 7. Pavement Section Statistical Analysis

Measurement	N	Geotextile		Control		Significance
		μ	σ	μ	σ	
Effective structural number, Month 0	11	2.10	0.19	1.95	0.11	Geotextile > control, $p = 0.031$
Effective structural number, Month 8	11	4.04	0.16	3.93	0.17	Geotextile > control, $p = 0.036$

N = sample size; μ = arithmetic mean; σ = standard deviation.

The difference in average effective SN (\overline{SN}_{eff-i}) between the control and geotextile sections before surface HMA construction was as follows:

Month Zero

$$\overline{SN}_{eff-geo} = 2.10 \quad \overline{SN}_{eff-control} = 1.95$$

$$\Delta\overline{SN}_{eff} = 0.15$$

This increment is added to the design SN (4.22), and assumed to be the effective SN (SN_{geo}^*) of geotextile sections with full pavement structure:

$$SN_{geo}^* = Design\ SN + \Delta\overline{SN}_{eff} = 4.37$$

The number of ESALs the structure with a geotextile may carry and the associated extension in service life can be computed using this effective SN and compared to the design ESAL load of 3,439,480 and a service life of 20 years:

$$ESAL_{SN_{geo}^*} = 4,257,172$$

$$\Delta ESAL = 817,692$$

$$\Delta Performance\ Period = 5\ years$$

The benefit can be further quantified by taking the ratio of the increased capacity to the original capacity, commonly referred to as the traffic benefit ratio (TBR):

$$TBR = \frac{ESAL_{SN_{geo}^*}}{ESAL_{Design\ SN}} \approx 1.24$$

Similarly, for the data gathered after 8 months,

Month Eight

$$\overline{SN}_{eff-geo} = 4.04 \quad \overline{SN}_{eff-control} = 3.93$$

$$\Delta\overline{SN}_{eff} = 0.105$$

$$\Delta Performance\ Period = 3\ years$$

$$TBR \approx 1.16$$

where

SN_a = average SN of lane a
 $ESAL_b$ = ESAL capacity of a pavement with SN b
 TBR = traffic benefit ratio.

From this analysis it can be seen that even very early in the life of a pavement, the geotextile has a measurable influence on the performance of the pavement; however, the reliability of the testing devices was not explicitly considered in this analysis. Direct numerical

comparisons should not be made between the two sets of FWD data, as each was performed on a different pavement structure during construction. Because it is unlikely that sufficient vehicular and environmental loading had been applied to cause severe intermixing and failure of the base course in the control lane, this FWD measured influence layer may show that the geotextile enabled better compaction and reinforcement of the aggregate layer in the northbound lane.

The testing of the prepared subgrade with a DCP revealed that the subgrade in the control lane was statistically equivalent to that of the subgrade of the adjacent geotextile lane in terms of resistance to penetration. After a geotextile was placed on the northbound subgrade and the aggregate base layer placed and compacted, the DCP again showed the performance of the two lanes to be equivalent. The measurements made by the FWD, however, showed a demonstrable improvement of the geotextile lane. The effective SN of the geotextile lane was found to be greater than that of the control lane at a p -value less than 0.05, and the apparent subgrade moduli of the two lanes were equivalent.

After 8 months of traffic, the statistical comparison indicated a modest improvement of the pavement structure attributable to the inclusion of a geotextile; however, this was not entirely unexpected. The mechanisms by which the geotextile is expected to provide benefit (separation, reinforcement, and drainage) require significant vehicular loading while the subgrade is soft. As most of the construction was performed in the drier, summer months, construction traffic was not expected to have significantly mobilized the separation benefit. Again, it is unlikely that sufficient conditions had occurred that would allow for the pumping of subgrade particles into the aggregate layer. Reinforcement, however, may have been mobilized by construction activities.

Benefit of Geotextile in Laboratory Testing for Variety of Pavement Structures

As mentioned earlier, load and deformation information were collected throughout the test for each samples. In addition, samples were visually inspected after they were removed from the mold to detect the possible intermixing of soil and aggregate. Permanent deformation measurements at 50,000 load cycles are noted in Table 8 for each sample in all three rounds of testing.

In Round 1 tests with the original aggregate gradation (VDOT 21B), the expected degradation of the aggregate layer and migration of soil were not observed. Visual observations after testing confirmed that even for the softest soil state, the aggregate layer effectively filtered out the soil particles and prevented pumping, regardless of the inclusion of the geotextile separator. Figure 11 shows the cross section of a tested sample without geotextile when the soil CBR was approximately 1.75.

Table 8. Permanent Deformation of Laboratory Test Samples

Subgrade CBR	Vertical Deflection Reading (in) at Cycles and Remarks About Intermixing						Permanent Deformation (in)		
	Control Sample			Geotextile Sample			Control	Geotextile	% Reduction
	0	50000	Remark ^a	0	50000	Remark ^a			
<i>High-Stress Lab Testing–Low Traffic (ADT = 650) Design and VDOT 21-B Aggregate</i>									
1.75	1.307	0.181	No	1.450	0.631	No	1.126	0.819	27
3	1.145	0.300	No	0.785 ^b	0.133 ^b	No	0.845	0.653	23
4	1.413	0.766	No	1.454	0.780	No	0.647	0.674	-4
5	1.343	0.822 ^c	No	1.552	1.099 ^c	No	0.521	0.453	13 ^c
9	1.325	1.006	No	1.435	1.108	No	0.319	0.327	-3
<i>Low-Stress Lab Testing–High Traffic (ADT = 1,800) Design and VDOT 21-B Aggregate</i>									
1.75	1.674	1.285	No	1.163	0.763	No	0.389	0.400	-3
3	1.524	1.160	No	1.680	1.385	No	0.364	0.295	19
4	1.580	1.167	No	1.843	1.306	No	0.413	0.537	-30
9	1.574	1.449	No	1.591	1.484	No	0.125	0.107	14
<i>Open-Graded Aggregate–High Stress (Low Traffic, ADT = 650) Lab Testing</i>									
1.75	1.394	0.975	Yes	1.381	0.992	Yes	0.419	0.389	7
3	1.728	1.228	Yes	1.374	1.083	Yes	0.500	0.291	42
6	1.426	1.142	Yes	1.369	1.130	Yes	0.284	0.239	16
9	1.505	1.291	Yes	1.486	1.306	Yes	0.214	0.180	16

ADT = average daily traffic.

^a Presence of intermixing of soil and aggregate at the interface.

^b The sample with geotextile was only 4 in high (2 in soil and 2 in aggregate) rather than 6 in high as with the other samples.

^c Deformation was measured at only 25,000 cycles.



Figure 11. Cross Section of Sample without Geotextile: CBR 1.75 Soil and VDOT 21-B Aggregate

In general, the samples with geotextile had less permanent deformation than the control samples with no geotextile. Figure 12 shows the deformation at different soil support conditions versus changing soil CBR values. There was an approximately 23 to 27 percent reduction in deformation as a result of the presence of geotextile when the CBR was 3 percent or less; there was no reduction in deformation for subgrade with a CBR of 4 percent and 9 percent; samples with geotextile had 3 to 4 percent more deformation. Although the sample with a subgrade CBR of 5 percent had a reduction of 13 percent, the sample was loaded for only 25,000 cycles compared to 50,000 for others. One other important discrepancy during this Round 1 test was that the soil for the CBR 3 percent geotextile sample was only 2 in high, compared to 4 in for all other samples.

Round 2 testing was for the pavement structures designed for higher ADT (1,800), which had a thicker pavement compared to those designed for 650 ADT. As a consequence, lower cyclic stresses were used for laboratory testing as low stresses were expected at the subgrade level from the thicker structure. Again, no intermixing of soil-aggregate was observed in any CBR samples regardless of the presence of geotextile. The permanent deformations are provided in Table 8 and plotted in Figure 13 for a relative comparison. Overall, the deformations were relatively lower than in Round 1, as was expected because of the low test loads. The results were inconsistent: a sample with geotextile had a larger deformation than the control sample at a CBR of 4 percent, whereas there was not much of a difference in deformation between control and geotextile samples with a CBR of 1.75 percent and 9 percent, respectively. On the contrary, the performance of samples with a CBR of 3 percent followed the expected trend, i.e., more deformation for the control sample than for the sample with geotextile. No explanation was found for such inconsistent behavior. Therefore, results were inconclusive for high-volume road designs.

When the aggregate gradation was modified to be more coarsely graded and more permeable, soil migration and aggregate protrusion were obvious, as shown in Figure 14. Although the geotextile had qualitatively reduced the amount of fine material pumping up into the aggregate layer, enough soil had migrated through the side of the mold for contamination to

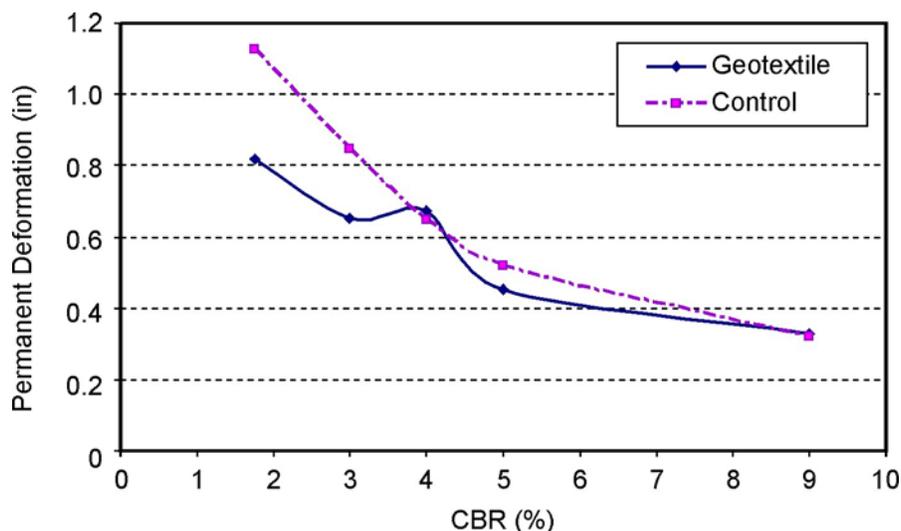


Figure 12. Permanent Deformation in Laboratory Samples with VDOT 21B Base for Low-Traffic (Average Daily Traffic of 650) Design. CBR = California bearing ratio.

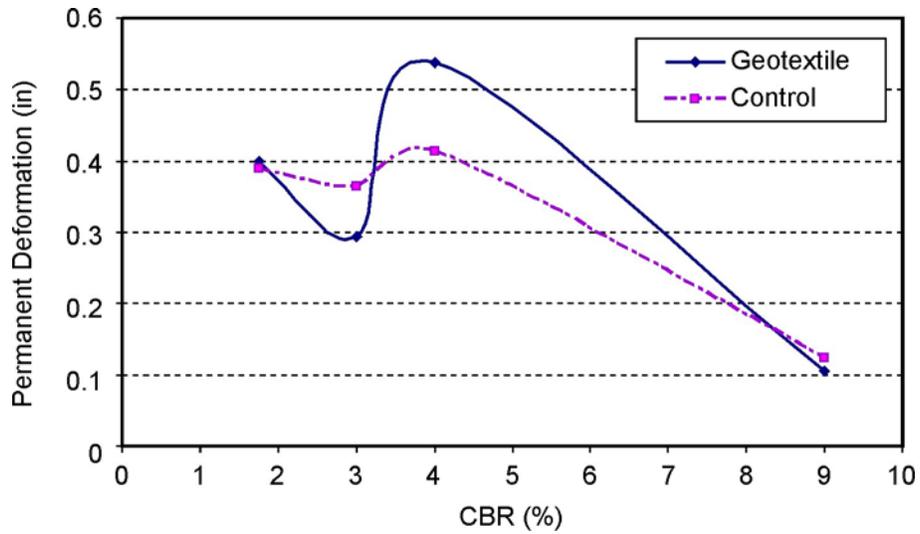


Figure 13. Permanent Deformation in Laboratory Samples with VDOT 21B Base for High-Traffic (Average Daily Traffic of 1,800) Design. CBR = California bearing ratio.

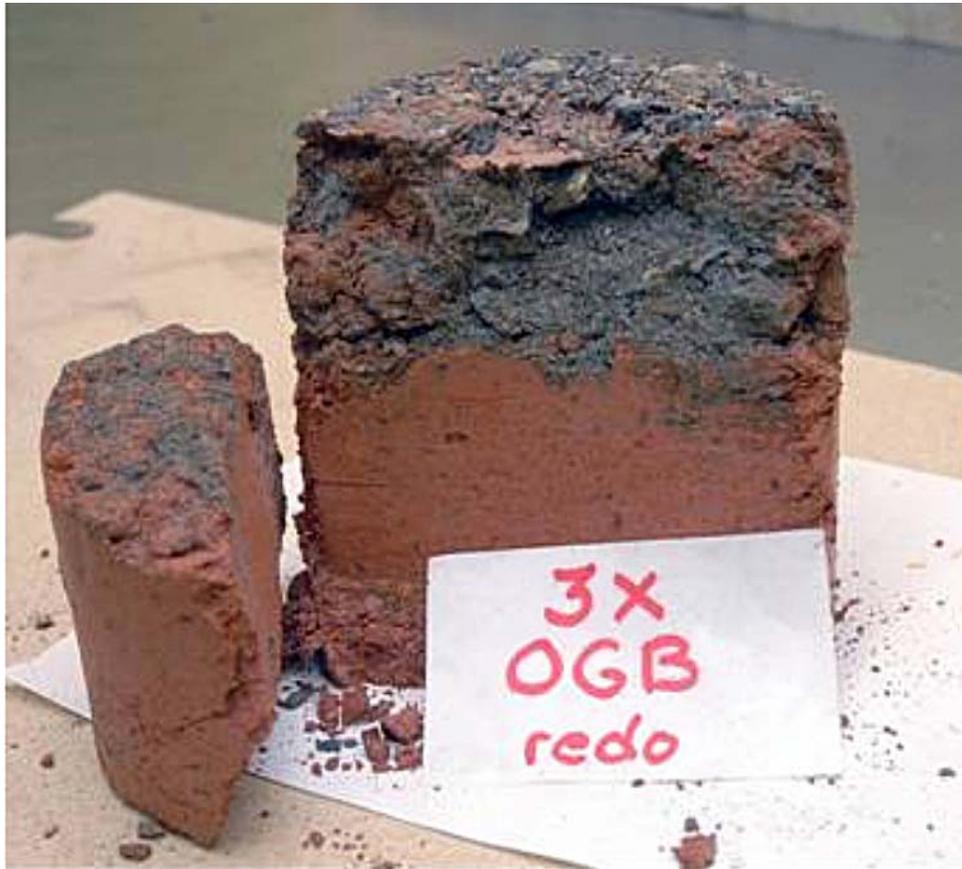


Figure 14. Intermixing of Soil and Aggregate in Open-Graded Base Laboratory Sample without Geotextile

be observed in the geotextile samples. Overall, the geotextile reduced the amount of permanent deformation as shown in Figure 15; the reduction was 7 to 16 percent except for the sample with a subgrade CBR of 3 percent where it was about 42 percent. The slipping of geotextile, shown in Figure 16, was evident in all cases except for the CBR 9 sample where no contamination was observed regardless of the presence of geotextile. Another interesting observation, shown in Figure 17, was the presence of more contamination on one side of the sample than the other for all six samples (both with and without geotextile) with CBRs of 1.75, 3, and 6 percent.

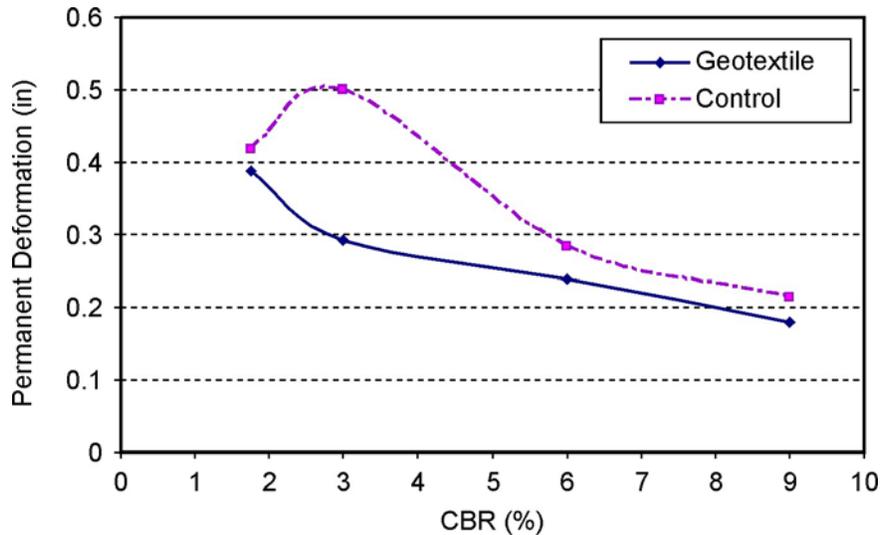


Figure 15. Permanent Deformation in Laboratory Samples with Open-Graded Base for Low-Traffic (Average Daily Traffic of 650) Design. CBR = California bearing ratio.



Figure 16. Slipping of Geotextile in Open-Graded Base Laboratory Sample

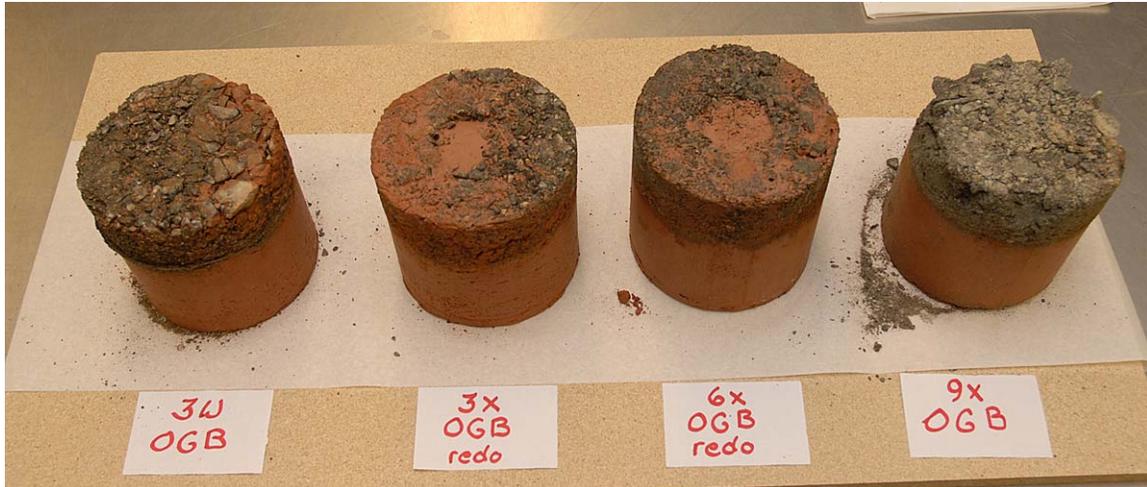


Figure 17. More Contamination on One Side of Open-Graded Base Laboratory Sample

CONCLUSIONS

- *After 8 months of traffic, additional service life appears to be gained from geotextile reinforcement.* The prevalence of dry conditions may reasonably be expected to limit the additional service life benefit from separation. A long-term field evaluation is needed to quantify the benefit.
- *Aggregate-soil compatibility appears to influence strongly the magnitude and mechanism of benefit that can be provided by a geotextile placed between the subgrade and base course.*
- *For lower permeability, densely graded aggregates (VDOT 21B) above subgrades with a CBR of 3 and lower, a geotextile appears to provide reinforcement to the soil-aggregate system by reducing permanent deformation by a minimum of nearly 20 percent.* This benefit occurs for pavement structures designed in accordance with the current VDOT *Pavement Design Guide for Subdivision and Secondary Roads in Virginia*⁸ with an ADT of 650.
- *The laboratory investigation was inconclusive.* Although fouling of the open-graded aggregate base with subgrade soil particles and downward penetration of aggregate particles were clearly demonstrated in the laboratory study with modified aggregate gradation, geotextile slipping and uneven contamination made a meaningful comparison inconclusive. In spite of open gradation of aggregate, neither contamination nor slipping was observed for stiff soil with a CBR of 9.
- *Although the benefit of the separation function was shown, the benefit could not be quantified with the laboratory setup used in this study.* The smaller sample size and difficulty of maintaining a proper boundary condition were possible reasons.

RECOMMENDATIONS

1. *VDOT's Maintenance Division should conduct at least an annual distress survey of the field test section used in this study to compare the performance of the control section with geotextile section.*
2. *VDOT's Materials Division should conduct at least annual FWD testing to compare the performance of the two sections.*
3. *VDOT's Materials Division should core the pavement to observe any changes in the aggregate layer including degradation of the subgrade-base interface and pumping of subgrade particles into the aggregate pore space when visible difference in surface distress are observed.*
4. *VDOT's Materials Division should carefully excavate and inspect the field test section at the end of the pavement service life or if failures occur.*
5. *The Virginia Transportation Research Council should provide technical assistance to VDOT's Materials Division for analysis and evaluation of the collected data at the end of the service life of the pavement.*
6. *VDOT's districts should pursue more trials of the use of geotextiles, especially on residential subdivision roads with a very thin pavement structure and soft soil support values (CBR 4 or lower would be better).*
7. *VDOT's districts should install more geosynthetics and monitor their performance to quantify the benefits of their use.*

SUGGESTIONS FOR FURTHER RESEARCH

- More research should be conducted to investigate the influence of sample size relative to the size of aggregate particles and loaded area. A full scale accelerated loading facility would be best for such an investigation, and efforts could be collaborated with the Turner-Fairbank Highway Research Center.
- More research should be conducted on the influence of soil properties, aggregate properties, and geotextile properties on geosynthetic use in pavements, perhaps in the form of a pooled effort among state departments of transportation.

COSTS AND BENEFITS ASSESSMENT

A costs and benefits assessment with regard to the use of the geotextile separators in this field project was not possible. The construction project was funded by the Charlottesville-Albemarle Airport, and the researchers did not have access to the detailed project construction

records that would allow for such an assessment. Further, measured benefits were likely constrained by dry weather during the study period, whereas the actual benefits of geotextile separators to the pavement's service life might reasonably be expected to increase with more normal precipitation.

Although unit cost information for geotextile is readily available (approximately \$0.66/ yd² including delivery), and although geotextile installation is relatively simple, it is expected that special handling requirements would add an installation premium to the cost of construction with geotextile because aggregate must be back-dumped, instead of spread using a conventional spreader box, to avoid damage to the textile.

Recent general costs and benefits assessments of geotextile separators have been made. Yang and Al-Qadi²⁴ computed complete life cycle costs (including agency and user costs) for pavements using two methods (the method used by Al-Qadi et al.²⁵ for stabilization by geotextiles and the method used by Perkins and Eden²⁶ for reinforcement by geotextiles) to quantify benefits in terms of increased pavement service life. Both methods showed that the use of a geosynthetic separator, particularly over a weak subgrade, increases pavement service life as measured by the AASHTO pavement design equation. In addition, using a modified AASHTO life cycle cost analysis methodology applied to 25 design combinations representing traffic features of secondary road pavements in Virginia, the use of the first method reduced agency costs by approximately 20 percent and the use of the second method predicted reductions between 0 and 40 percent. For user costs, the first method demonstrated a 70 percent reduction and the second method predicted a 0 to 100 percent reduction.

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