ENGINEERING
BULLETIN

Propex®
GEOSOLUTIONS

EB123 - QUANTITATIVE PROOF OF IMPROVED PERFORMANCE OF FLEXIBLE PAVEMENTS

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY RESEARCH STUDY

Virginia Polytechnic Institute and State University performed laboratory and field research in cooperation with the Virginia Department of Transportation between 1993 and 1998 to quantify the life cycle cost benefit of including geosynthetics within flexible pavements. The research was a cooperatively funded effort by Propex, Atlantic Construction Fabrics, and the state of Virginia through The Virginia Center for Innovative Technology. Both geotextiles and geogrids were tested and compared to control sections containing no geosynthetics. The results of the five-year study are summarized in the Executive Summary for the final report by Imad L. Al-Qadi, et.al. Information from that Executive Summary was used to compile this Engineering Bulletin.

BACKGROUND

Roadway systems, permanent and temporary, derive their support from the underlying subgrade. The overlying structural layers of bound pavement and/or unbound aggregate provide a riding surface while distributing the traffic loading over the subgrade. Most flexible pavement systems consist of three general material layers: subgrade, unbound or treated aggregate, and bound pavement. The pavement system maintains its serviceability until one or more of the layers fail to perform its function. Each material layer has its own distinct mode(s) of failure.

The subgrade soil fails in shear when its shear strength is exceeded by a load, resulting in a bearing capacity failure. The shear strength of most subgrade soils is lowered as the water content of the soil increases beyond optimal moisture conditions. The way to minimize subgrade failure in a roadway system is to accurately determine the subgrade soil strength and simply keep the loading applied to the subgrade, under different environmental conditions, less than what would cause a bearing capacity failure. Secondly, minimize the subgrade's exposure to moisture, which can lower the soil's shear strength and bearing capacity. In addition, minimizing exposure to moisture can reduce the erosion of the subgrade by pumping and jetting. The bound layers in a flexible pavement, such as an asphalt concrete wearing course, binder layers, and stabilized layers such as cement treated layers, fail in tension, progressively cracking until their functionality is unacceptable. Although layers of these bound materials must be able to bend somewhat in a flexible pavement, too much bending or movement will readily crack these layers since these materials are quite weak in tension. In areas of extreme temperature swings, expansion and contraction of the pavement layers can cause horizontal movement that can cause thermal cracking. Also, the bound pavement layers can fail internally, resulting in shoving, flow rutting, stripping, and/or binder cracking due to aging or hardening. However, the predominant cause of failure of bound pavement layers is traffic loading and inadequate structural support from underlying layers. Therefore, like the subgrade layer, the bound layers will continue to perform adequately for long periods if the pavement is designed with sufficient wearing surface and underlying load spreading structural layers to prevent over stressing and bending.

LABORATORY STUDY

In 1993, geotextile and geogrid stabilized flexible pavement sections (total 18 sections including the control sections without geosynthetics) were evaluated in the Virginia Tech laboratory to determine benefits of geosynthetics when used at the aggregate-soil interface. Laboratory flexible pavement sections were constructed (Figure 1), tested, and analyzed to assess the geosynthetic's effectiveness on pavement performance. The pavement sections were designed to model typical low- volume traffic, secondary road, built over a weak silty sand subgrade. The test sections were constructed using different base course thicknesses and subgrade California Bearing Ratio (CBR) values, ranging from 2 to 5.8%. The pavements were dynamically loaded at a frequency of 0.5 Hz using a computer-controlled pneumatic loading system. A force of approximately 9,000 lbs (40 kN) was applied to the pavement through a 12 inches (300mm) diameter rigid plate. This system modeled the dual tire load from an 18 kip (80 kN) truck axle. Surface deflections were measured during loading using a Linear Variable Displacement Transformer (LVDT) array. Using pavement response to loading data, the performance of the pavement sections was assessed based on 1993 AASHTO design procedures and linear viscoelastic analysis procedures. A service-life cost criterion was used to compare the performance of the test sections.

Compared to control test sections, the number of equivalent single axle loads (ESALs) applied to reach the same rutting failure (1 inch [25mm]) of the pavement was slightly higher when a geogrid was used in the pavement section, while it was significantly greater (approximately two times) when a woven geotextile was used.

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Although this improvement was noticed to be independent of subgrade strength within the range evaluated, it is believed that geotextile benefits are more pronounced at weaker subgrades (Figure 2). The study also concluded that the separation function provided by geotextile is a key component for improving the performance of a pavement section built over a weak silty sand subgrade. The value of the separation function may be realized in a short term in a pavement system or may prove to be a longer term benefit depending on the subgrade soil type and moisture content. The separation benefit is even more pronounced when an open free-draining aggregate, as recommended by AASHTO, is used. Similarly, the stabilization benefit of the geotextile is more pronounced over weak subgrades. However, long term stabilization benefits of local reinforcement, confinement and lateral restraint greatly extend the life before significant rutting occurs even in pavements over competent subgrades. By maintaining and enhancing the resilient modulus of the unbound aggregate layer through separation and stabilization, the geotextile was able to greatly extend the pavement service life at a fraction of the cost of rehabilitating the pavement section built without a geosynthetic (using an overlay) to achieve the same service life.

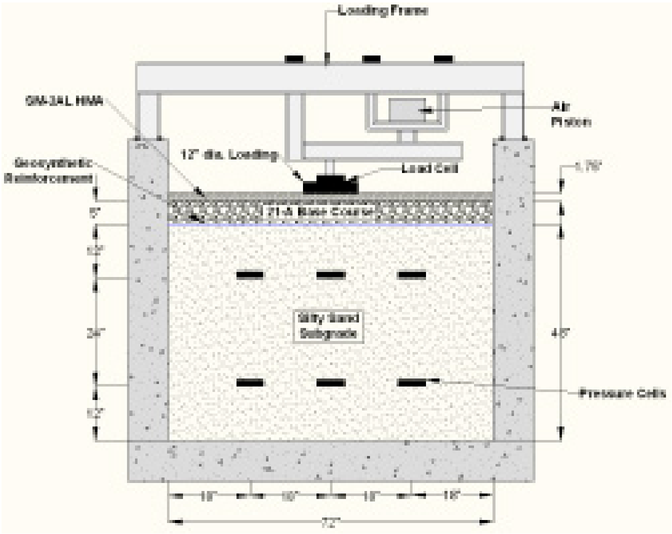

Figure 1 - Schematic of the Laboratory Loading System

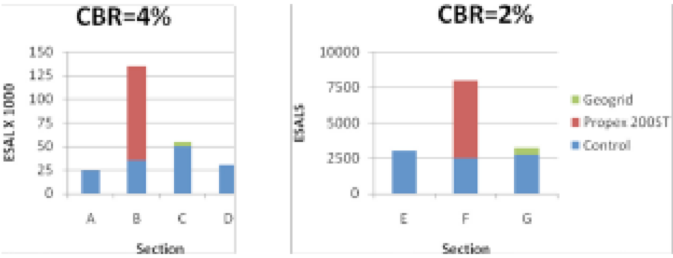

Figure 2 - Performance Comparisons

FIELD STUDY

To verify the laboratory study, in June 1994, a 492 ft (150 m) long secondary road pavement section was built, as part of the realignment of routes 616 and 757 in Bedford County, Virginia to evaluate the field performance of geosynthetically stabilized flexible pavements (Figure 3 and Table 1). The CBR of the subgrade after construction preparation was approximately 8%. The pavement section was divided into nine individual sections, each approximately 49.2 ft (15 m) long. Sections one through three have a 4 inch (100mm) thick limestone base course (VDOT 21-B), sections four through six have a 6 inch (150mm) thick base course, and sections seven through nine have an 8 inch (200mm) thick base course. Three sections were stabilized with geotextiles and three with geogrids at the base course/subgrade interface. The remaining three sections were kept as control sections. One of each stabilization category was included in each base course thickness group. The hot-mix asphalt (HMA), SM-2A, wearing surface thickness was 3-3.5 inches (78-90mm). The outside wheel path of one lane was instrumented with strain gages, pressure cells, piezoelectric sensors, thermocouples, and moisture sensors. A data acquisition system was used to collect instrument responses on site and transfer the responses to Virginia Tech using a modem. Calibration response from the piezoelectric sensors was used to develop characteristic master curves for determining the approximate axle load and the tire pressure range for random traffic traveling on the test section and for a series of controlled traffic loadings.

Section monitoring, based on the instrumentation response to control and normal vehicular loading, indicated that geosynthetic stabilization provided significant improvement in pavement performance. Generally, the measured pressure below the base course-subgrade interface for the geotextile-stabilized sections was lower than for the geogrid stabilized and control sections with comparable pavement structural sections. This finding was in agreement with other measurements, such as surface rut depth, ground penetrating radar (GPR) survey, and falling weight deflectometer (FWD) survey. The control section (4 inch [100mm] thick base course) exhibited more severe rutting than the geosynthetically stabilized sections. The GPR results imply that more contamination has occurred in the control section as compared to the sections stabilized with geosynthetics. Falling weight deflectometer back-calculation revealed weaker pavement system for the geogrid-stabilized and control sections than for the geotextile stabilized sections over the three-year evaluation period. The measured deflections were analyzed using the MODULUS back-calculation program. The results were further analyzed using linear elastic and viscoelastic programs to determine the extent of base course contamination by subgrade fines.

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To quantitatively assess the extent of contamination, excavation of the first three sections was conducted in October 1997. Gradation analysis, on base course and subgrade samples obtained at different depths, revealed that fines present in the base course aggregate layer were significantly greater in the control and geogrid-stabilized sections than in the geotextile- stabilized section. As a result of the gradation analysis of the underlying subgrade, it is believed that the subgrade fines present in the base course may be pumped from a depth greater than 6 inches (150mm) inside the subgrade. These findings led to the conclusion that an effective separation geotextile would prevent fines migration and maintain the strength of the aggregate base, given that it is installed properly and meets construction survivability criteria.

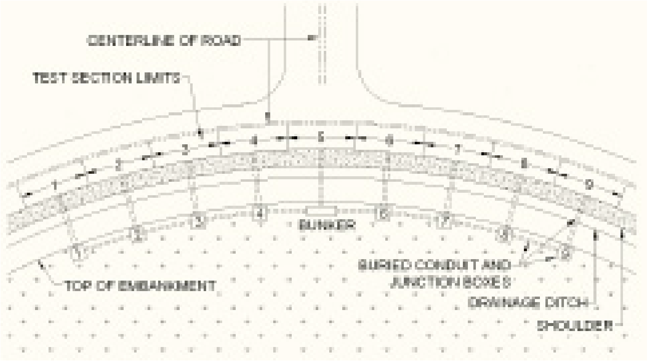

Figure 3 - Layout of the Test Sections and Support Structures

Section No.	Stabilization	Base Course Thickness (mm)
1	Control	100
2	Geotextile	100
3	Geogrid	100
4	Control	150
5	Geotextile	150
6	Geogrid	150
7	Control	200
8	Geotextile	200
9	Geogrid	200

Table 1 - Initial Design of Instrumented Sections

Analysis of ESALs to reach 0.80 inch (20mm) rutting in the test pavement indicated that the geogrid-stabilized section carried 82% more ESALs before failure than the control section, while the geotextile-stabilized section carried 134% more ESALs before failure than the control section. Also, it is important to point out that sections stabilized with geotextiles have reached an equilibrium condition, where the separation and stabilization benefits will continue indefinitely, keeping the pavement structural section as built. Similar hypothesis could not be made for geogrid stabilized and control sections, as the process of soil migration and aggregate penetration into the subgrade may continue indefinitely.

LIFE-CYCLE COST BENEFIT

To put the cost benefits of the geosynthetics into perspective, the pavement service life improvement must be quantified and compared to the cost of achieving these improvements. In AASHTO pavement design, the amount of additional base and/or subbase aggregate required to increase the pavement structural numbers, to achieve design service life extensions comparable to those achieved with the inclusion of a geosynthetic, is quantified as discussed below. Besides the additional aggregate required to get comparable performance, the cost of extra excavation is often needed to accommodate the additional aggregate thickness. The installed cost of the geotextile used in this research is approximately equal to the cost of 2 inches of VDOT 21-B base course aggregate, while the geogrid used cost approximately the same as 5 to 6 inches of the base course. Based on performance and cost analysis, the life-cycle cost of the geotextile stabilized pavement is significantly lower than both the unstabilized pavement, and the geogrid stabilized pavement. This justifies the use of geotextiles for separation/stabilization in our roads.

DESIGN METHOD

Based on the results of the study, a design method for geotextile stabilized roads was developed by Dr. Al-Qadi, at Virginia Polytechnic Institute and State University. Although the development of the procedure considered the viscoelastic behavior of HMA, the pavement design procedure is based on the AASHTO-93 design guidelines. Laboratory and field observation and evaluation validated this method as to the use of geotextiles for separation and stabilization. These tightly controlled laboratory and field trails resulted in performance curves comparing calibrated actual loadings to pavement design loadings (ESALs), based on AASHTO-93, for sections with geotextiles, and sections without geotextiles. These performance curves were combined to form the design curve depicted in Figure 4, where traditional design ESALs (without a geotextile inclusion) are compared to design ESALs when a geotextile is incorporated. To use Figure 4, the designer determines the design number of ESALs using AASHTO traffic loading criteria. That design number of ESALs is then used as the without-geotextile, y-axis, value and the corresponding higher, with-geotextile ESAL value is determined from the x-axis. What this means is, if a geotextile is incorporated into an AASHTO design, the actual service life achieved will be significantly longer, as depicted by the higher number of ESALs on the x-axis needed to achieve the same failure.

Conversely, if the AASHTO design number of ESALs are used as the with-geotextile (x-axis) value, the corresponding y-axis (traditional without-geotextile) value represents the lower

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number of ESALs, which would become the new required design value. Use of the lower design number of ESALs would allow a reduction in required pavement structure thickness (lower structural number [SN]), to achieve the same service life, if a geotextile is included in the design.

The extended service life depicted in Figure 4 is attributable to the separation and stabilization benefits of placing a geotextile at the subgrade/base aggregate interface. Significant further pavement enhancement may be achieved, as the use of a geotextile separator also allows the use of a more appropriate open, free-draining aggregate. The free draining aggregate is much more structurally efficient and results in a greater structural number contribution in an AASHTO pavement design.

This is because the assigned AASHTO drainage coefficient, m, which corrects for the drainability of unbound aggregate layers, is much larger in free draining aggregates. Free draining aggregate layers can be assigned up to 2 to 3 times the design structural strength, per unit thickness, compared to poorly-draining aggregates.

Finally, the benefits of using a separation/stabilization geotextile demonstrated by this research are dependent upon the installation and long term durability of the geotextile. It is recommended the AASHTO M 288 National Geotextile Guideline Specifications be followed, to assure geotextile survivability.

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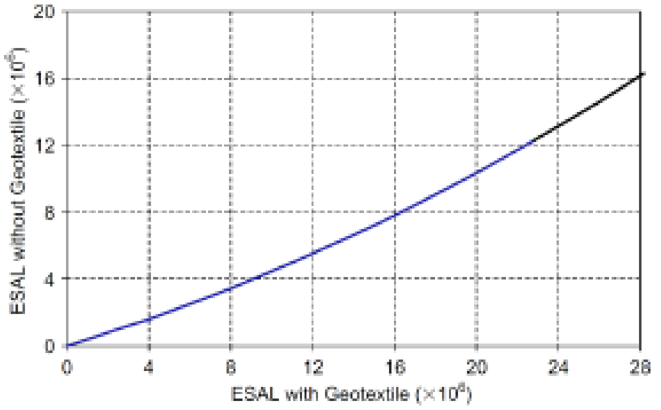

Figure 4 - Service life comparison by ESALs – With and without a separation/stabilization geotextile

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