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The proper use of geosynthetics in flexible pavements

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ABSTRACT : Geosynthetics have been used in roadway systems for reinforcement, layer separation, drainage, stress relief, and as moisture barriers. For separation function, the proper geosynthetic prevents the subgrade soil fines from migrating into the unbound aggregate layers, and prevents the aggregate of this layer from penetrating into the subgrade while allowing free water movement. To reinforce aggregate layers, the geosynthetic should be applied within the aggregate layer at the highest shear location. The geosynthetic may enhance the interlock, but it may also introduce a slippage plane. Impermeable geosynthetic application underneath an open-graded drainage layer for pavement built on a subgrade with a low water table level would significantly improve the pavement performance. The use of a geosynthetic drainage layer, at the appropriate location within the pavement system, appears to be promising. For cracked surfaces, it is vital to correctly bond the reinforcement to the overlay to make it effective. However, a low modulus geosynthetic that has the appropriate thickness would dissipate most of the available strain energy at the crack tip. The potential stripping in HMA, excessive deflection, failure in the pavement materials, and compatibility and appropriate use of geosynthetics in pavements should not be overlooked.

1 INTRODUCTION

With an aging transportation infrastructure, increasing travel demand, and diminishing financial resources, there is a need to optimize the return from the investment in the transportation infrastructure. Utilizing new technologies to improve pavement performance and increase its service life has recently become an important part of designing and rehabilitating the pavement systems. In the past three decades, many different technologies have been introduced and presented as systems that may improve pavement performance and reduce current premature failures. These technologies include different types of geosynthetics. While many of these technologies may provide benefits such as increased pavement performance, or reduced effective annual cost, some have provided little benefit and, in some cases, have been detrimental. Therefore, not all geosynthetics have been welcomed by engineers in the US; the reasons for this are twofold. First, the technology has been oversold in several occasions. That is, while the concept of improving pavements is certainly attractive, there is a great gap between concept and field implementation. In short, there was too much attention given to the “glamour” of the new applications, their basic properties, which may not be related to field performance, and the “claimed” immediate savings. In addition, insufficient attention has been paid to the engineering details, the proper design that makes them operational and effective systems, and their accurate life-cycle-cost analysis. A second detracting factor has been the lack of well-thought-out programs to quantify benefits and develop designing concepts that are integrated with existing pavement design guidelines. Thus, the presented benefits were anything but quantitative.

In pavement systems, various geosynthetics are used to provide reinforcement that increases the tensile strength of a particular layer; strain energy absorption between pavement layers; separation, which maintains the integrity of particular layers by preventing intermixing; drainage/ filtration, which allows the water to flow, thus dissipating pore water pressure while limiting soil movement; and/or a moisture barrier, which prevents water movement between layers. In this paper, a state-of-the-practice on the use of geosynthetics in pavements and the effectiveness of such a practice are presented with attention given to the correct application based on scientific rather than empirical approaches for separation, reinforcement, waterproofing, and strain relief.

2 STABILIZATION

The misconception in conventional layered pavement designs is that respective layers of various pavement components will remain unchanged over the existing subgrade throughout the service life of the pavement. Changes in load and environment may cause pavement systems to fail at the aggregate base-subgrade interface. For the aggregate layer to be effective in distributing stresses from surface loading, it must remain relatively permeable and its design thickness and strength must be maintained. If the stress reduction function is not maintained, excessive subgrade deformation may occur, resulting in pavement rutting and pavement surface distresses.

When designing roads on weak subgrade soil, a common practice of State Department of Transportation (DOT) engineers has been to include an extra amount of "sacrificial" aggregate in addition to the amount required by standard design methods (FHWA, 1993). Without this practice, a significant portion of the base/subbase course aggregate may be lost to the weak subgrade through aggregate penetration or subgrade soil pumping, thereby effectively reducing the ability of the base course to distribute traffic loading stresses. According to a survey, DOT engineers anticipate significant aggregate loss when the strength of the subgrade soil is equivalent to a California Bearing Ratio (CBR) of 3% or less (FHWA, 1993).

In the absence of a base course-subgrade separator, two mechanisms may tend to occur simultaneously over time in pavements (Al-Qadi *et al.*, 1994): soil fines attempt to migrate into the base course aggregate, thereby affecting the drainage capability of the pavement as well as its structural capacity; and the aggregate tends to penetrate into the soil due to local shear failure (Figure 1). A base contamination that increases the percent fines passing #200 sieve to 13% can significantly alter the structural capacity of the base layer (Jorenby and Hicks, 1986). This effect has been noticed with a subgrade CBR up to 8% (Al-Qadi *et al.,* 1998). In addition, if the soil fines are carried upward into the base course aggregate voids and reach the hot-mix asphalt (HMA) layer, emulsification of the asphalt binder may result in stripping in that layer.

When a geotextile is used within the aggregate layer, unsatisfactory performance is expected as the geotextile acts as a slippage surface in such an application, and this may cause early failure.

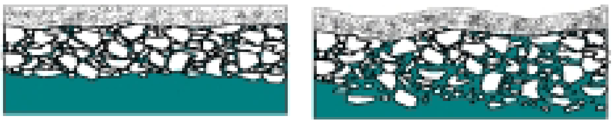

Figure 1 Aggregate intrusion and subgrade soil pumping.

In summary, the performance of a geosynthetic as a separation layer and its contribution to the road structure are largely dependent on the subgrade material (strength, particle size and distribution, plasticity, and moisture content), the aggregate base layer characteristics (gradation, percent fine, maximum aggregate size, and aggregate angularity), the magnitude and number of loadings during the service life of the road, and the environmental conditions. Geosynthetic separators must always allow free water movement. Depending on the subgrade soil type and moisture content, the value of the separation function may be realized in a pavement system during its early service life or may prove to be a longer term benefit.

3 AGGREGATE REINFORECEMT

Geotextiles, geogrids, or combinations of both have been used to reinforce aggregate layers in flexible pavements. Several researchers have suggested that geosynthetic reinforces pavement systems when used in aggregate layers (Barksdale *et al.,* 1989; Hass, 1987; Webster, 1991). This reinforcement can be classified as base and subgrade restraint, lateral restraint, or membrane type support (Christopher and Holtz, 1991; Giroud, 1987). It has also been suggested that interlocking (friction) between the aggregate-geosynthetic and soil-geosynthetic surfaces may minimize lateral spreading of the aggregate and soil.

Tensioned membrane reinforcement is a characteristic of both geotextiles and geogrids, and is a function of the geosynthetic's tensile modulus. The vertical resultant of the membrane resisting stress may act to help support vehicular loading. However, it has been suggested that the tensioned membrane effect is negligible unless a rut depth of at least 75 to 100 mm is developed (Christopher and Holtz, 1991; Giroud and Bonaparte, 1984; Holtz and Sivakugan, 1987). Because of this requirement for a relatively high deformation, tensioned membrane reinforcement is not usually considered a significant factor in low deformation road systems such as flexible pavements. For large vehicular loads on unpaved roads where deep ruts (> 100 mm) may occur, the reinforcing functions become increasingly more important if stability is to be maintained. Significant misunderstanding is still present in this mechanism as current equations used to calculate horizontal stresses are based on static loading on homogenous layers; Taylor equations presented in 1948 were used to explain the membrane reinforcement.

The shear type of reinforcement provided by geosynthetics is purported to laterally confine base course aggregate. Thus, the grid system may provide benefits to the pavement system, especially in areas were high shear is expected. The restriction of lateral movement is thought to result from the interlock that occurs when aggregate particles are bound within the geogrid apertures (Kennepohl *et al.,* 1985; Hass *et al.,* 1988). These benefits are thought to increase with the increasing angularity of the aggregate.

Carrol *et al.* (1987) stated that "the principle of confinement is best illustrated by a pyramid of billiard balls held together at their base by a plastic ball rack. Without a rack at the base, the pyramid of balls would collapse under its own weight; the rack provides confinement against lateral movement at the pyramid's base." Such an analogy can be easily misleading; as the pavement system is always confined. This analogy should not be applied to layered systems as pavements, which usually have partial friction at the interfaces. A high strength, high modulus geosynethtic with good friction or one that interlocks with the aggregate, and with less susceptible to creep over time or load repetition, would be required. The importance of the reinforcing geosynethtic may diminish as the pavement thickness increases (more confined) and as stresses at the interface decrease. Therefore, such an application would be most beneficial to pavement exposed to heavy loading and/or underdesigned pavement such as unpaved roads.

In addition, a geosynthetic that provides tensioned membrane or shear type support to surface loads experiences both constant and dynamic tensile stresses. Therefore, creep of the polymeric material must be considered to account for the stress relaxation, which is a function of time, temperature, load frequency, and stress applied. The consequence of geosynthetic creep is stress relaxation.

In summary, although a geosynthetic may initially provide reinforcement in a road section, the significance of the reinforcement may reduce over time due to geosynthetic creep and subgrade consolidation. These effects should be considered in any future mechanistic pavement design.

4 PAVEMENT DESIGN WITH GEOSYNTHETICS

All roadway systems, permanent or temporary, derive support from the underlying subgrade. Thus, the geosynthetic functions in pavements are similar for either temporary or permanent pavement systems. However, the design methods for both pavement types are different due to difference in allowable rutting and other failure criteria. Several design methods have been proposed based on practical experience, theoretical studies, or limited laboratory testing (FHWA, 1993; Steward *et al.,* 1977; Giroud and Noiray, 1981; Christopher and Holtz, 1991; Hass *et al.,* 1988; Hass, 1987; Barksdale *et al.,* 1989; Webster, 1991; Sellmeijer, 1990). Manufacturers promoting the use of their particular products have introduced most of the design approaches.

A design method for geosynthetically stabilized secondary roads was developed by Al-Qadi *et al.* (1997). Although the development of the procedure considered the viscoelastic behavior of HMA, it is based on the 1993 AASHTO pavement design guidelines. Smith (1994) reports detailed analysis of the 18 sections used in the testing to develop the method. The method was field validated at the instrumented road in Bedford, Virginia.

In the lab, compared to control test sections, the number of equivalent single axle loads (ESALs) applied to reach the same rutting failure (25 mm) of the pavement was higher when a geogrid was used in the pavement section. This was significantly greater (approximately two times) when a woven geotextile was used. Although this improvement was noticed to be independent of subgrade strength within the range evaluated (CBR = 2-6%), it is believed that geotextile benefits are more pronounced at weaker subgrade soils.

In the field instrumented sections (Al-Qadi *et al.*, 1998), the measured pressure below the base course-subgrade interface, rut depth, ground penetration radar (GPR) survey, and falling weight deflectometer (FWD) survey showed that the control section (100 mm-thick base course) exhibited more severe distress than the geosynthetically stabilized sections. Field excavation four years later and gradation analyses, on base course and subgrade samples obtained at different depths, revealed that fines present in the base course were significantly greater in the control and geogrid-stabilized sections than in the geotextile-stabilized section.

Analysis of accumulated ESAL (to reach 20 mm rutting in the field 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. Those results were in agreement with the laboratory results.

The laboratory and field testing resulted in performance curves comparing calibrated actual loadings to pavement design loadings (ESALs) for sections with and without geotextiles. The performance curves were combined to form the design curve depicted in Figure 2, where traditional design ESALs (without a geotextile inclusion) are compared to design ESALs that incorporate a geotextile.

To use Figure 2, the designer determines the design number of ESALs using AASHTO traffic loading criteria. This design number of ESALs is then used as the "with-geotextile" y-axis value, and the corresponding lower traditional ESAL value is determined from the x-axis. Using the lower design number of ESALs would allow a reduction in required pavement structure thickness (lower structural number [SN]) in order to achieve the same service life, if a geotextile is included in the design. Conversely, if the AASHTO design number of ESALs is used as the traditional "without-geotextile" x-axis value, the corresponding y-axis "with-geotextile" value represents the higher number of ESALs, which would become the new, required design value. What this means is, if a geotextile is incorporated into the AASHTO design, the actual service life achieved will be longer as depicted by the higher number of ESALs on the y-axis. It is more cost effective to use geotextile with the actual designed ESAL to increase the service life of the pavement and hence to reduce the effective annual cost.

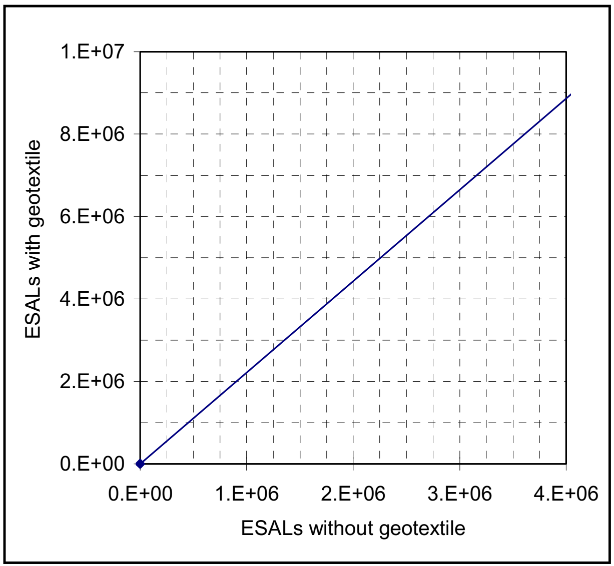

Figure 2 geotextile contributions to flexible pavements

To put the cost benefits of the geosynthetics into perspective, the pavement service life improvement must be compared to the cost of achieving the improvement. It is misleading to compare the cost of the geosynethtic used to the total reduction of the aggregate thickness. The comparison should be based on the performance and life-cycle cost analyses.

A program (GeoPave) has been developed that allows for design with and without geosynthetics and considers the environmental effect. It also compares the annual cost and the life-cycle cost of alternative designs with the option of including future overlay.

5 DRAINAGE

One of the most influential factors contributing to the deterioration of existing pavements is moisture within the pavement system. The concerns associated with excessive moisture in pavements have been understood since the early days of the interstate building era in the United States. A report containing data from the AASHO Road Test (Liddle, 1962) in the early 1960s showed that rates of serviceability loss were 40 to 50 times greater during the spring thaw than during summer months when less or no free water is available in the pavement system. Even in the present day, roads tend to be designed with the pavement strength in mind and the accompanying presumption that sufficient strength will give enough support to counter the effects of poor pavement drainage. Forsyth (1987) projected that over 65% of the $329 billion estimated on road repairs in the United States between 1976 and 1990 could have been saved if high-use pavements were designed with proper drainage.

Moisture may enter through various points into the pavement structure, such as surface infiltration and through cracks, joints, and shoulders. Interrupted aquifers, springs, and drainage in cut areas may also have an effect on pavement moisture. Excessive moisture in pavements can cause one or more of the following forms of deterioration: reduction of the shear strength of unbound subgrade and base/subbase material; differential swelling in expansive subgrade soils; movement of unbound fines into flexible pavement base/subbase courses; frost heave and reduction of strength during frost melt; pumping of fines and durability cracking in rigid pavements; and stripping of asphalt binder in flexible pavements.

Nowadays, drainage systems such as permeable aggregate bases (asphalt or Portland cement treated) and edge drains are common additions to flexible pavement design. In addition to these drainage practices, the use of geosynthetic materials may be beneficial. The research at the Virginia Smart Road (Al-Qadi *et al.,* 2001) has shown that a pavement drainage system composed of a permeable asphalt-treated drainage layer backed by a geocomposite membrane appears capable of removing drainable water from the pavement system while providing a dry service condition for the underneath layers even in the event of heavy rain. Evaluation of the geocomposite membrane effectiveness as a moisture barrier was based on ground penetrating radar (GPR) surveys and continuous moisture monitoring using time-domain reflectometry (TDR) (Elseifi *et al.,* 2001).

A triplanar geonet drainage composite layer has been proposed recently to replace the open-graded drainage layer in flexible and rigid pavements. Although other locations have been suggested for its application within the pavement system, one needs to consider the optimum location based on the project characteristics, pavement slope, subgrade material, environmental condition (potential frost heave and swelling), and vehicular loading. In addition, the ability of the geonet to withstand the HMA placement temperature (if installed underneath HMA), creep, and fatigue loading cycles dictate the service life of the geonet life.

To conclude, soil fines need to be prevented from being pumped into free-draining aggregate in order to maintain the layer's drainage capability and its structural function of distributing the stresses of surface loading. Thus, the best application would be to use an impermeable geosynthetic membrane underneath an open-graded drainage layer. The use of geosynthetics in or underneath HMA layers to provide surface impermeability should be carefully evaluated on a case by case basis to prevent potential stripping in the HMA and/or slippage at the interface. This particular benefit of geosynethtic can be detrimental if used inappropriately or in the wrong application. The use of a geosynthetic drainage layer appears to be promising.

6 REINFORCEMENT/ STRAIN ENERGY ABSORPTION FOR OVERLAYS

The rapid deterioration of the US highway system, the majority of which was originally constructed during the 1950s and 1960s, justifies the need for more effective pavement rehabilitation methodologies. In recent years, interlayer systems have received considerable attention as viable solutions to enhance flexible pavement performance. In HMA applications, interlayer systems are thought to provide reinforcement (by increasing the tensile strength or stiffness of a particular layer) and strain energy absorption between pavement layers. Several successful and non-successful applications have been reported. The application of geosynthetic as an interlayer system in HMA is more critical than at the subgrade-aggregate interface due to the greater tensile strain at the upper layers. Potential disadvantages may occur due to improper asphalt distribution (which causes slippage) and during HMA recycling.

The evolution of a crack in a HMA overlay consists of three distinct phases: the non-affected phase, the crack initiation phase, and the propagation phase. There are several ways that geosynthetics affect cracks that propagate through pavements: a crack propagates from old pavement through geosynthetics (stress relief); a crack from old pavement stops at geosynthetics and another crack starts from the top (stress relief); a crack propagates from old pavement and spreads horizontally at geosynthetics (stress relief); a crack propagates from surface to bonded geosynthetic (reinforcement); and a delay a crack initiates from the bottom of the layer (reinforcement).

Geosynthetics have been found effective in retarding reflection cracking. Geosynthetic mechanisms depend on the cracking type. A cracked body can be loaded in one or a combination of the three displacement modes: Mode I loading (opening mode) results from loads that are applied normally to the crack plane; Mode II loading (sliding mode) results from in-plane shear loading, which leads to crack faces sliding against each other normal to the leading edge of the crack; and Mode III loading (tearing mode) results from out-of-plane shear loading, which causes sliding of the crack faces parallel to the crack leading edge. The last mode is negligible for cracking in pavements.

The presence of a low modulus geosynthetic above an old pavement has been shown to reduce the tensile stress at the tip of the crack. This decreases the stress intensity factor, thereby reducing crack growth. Theoretically, a thicker fabric would result in lower stress at the tip of the crack. For a geosynthetic to perform efficiently as a stress relief layer, its stiffness should be low. This can be achieved by increasing the asphalt retention rate (but with a caution of causing slippage problems). However, the softer the geosynthetic, the greater the pavement system deformation under loading will result. The relationship between stiffness and stress relief has been verified by finite element analysis and field analyses (Al-Qadi and Elseifi, 2002). However, some have reported that geosynthetics are effective in retarding fatigue and longitudinal cracking, but not as effective in transverse and low temperature cracking. Again, this is dependant on the geosynthetic type and the developed strain at the surface.

In summary, due to traffic and thermal loading, an existing crack moves horizontally and vertically, and low stiffness geosynthetic may dissipate most of the available strain energy through deformation within the interlayer. If the crack re-initiates at the bottom of the overlay, the required number of cycles for the crack to initiate is extremely high when the geocomposite membrane is used, given that geosynthetic has the appropriate thickness and properties. Nevertheless, other modes of failure (such as fatigue of the overlay) should not be ignored or overlooked as these will require the geosynthetic or other interlayer materials to act as reinforcement.

7 SUMMARY

To optimize the benefit-cost ratio of using geosynthetics in pavements, it is important that geosynthetic with the appropriate characteristics and properties be specified for the exact locations in the pavement systems. For separation at the interface of subgrade-aggregate base layer, the geosynthetic should prevent intermixing at that location while allowing free water movement. For aggregate reinforcement, geosynthetics may be used within the aggregate layer at the highest shear stress location. Using geotextile within the aggregate layer is not recommended. The application of impermeable geosynethtic underneath open-graded drainage layer (given that the water table level is low) would significantly improve the pavement performance. The use of a geosynthetic drainage layer, at the appropriate location within the pavement system, appears to be promising. For overlays applied to cracked surfaces, bonding of reinforcement to the overlay is very important. On the other hand, a low modulus geosynthetic that has the appropriate thickness is able to dissipate most of the available strain energy at the crack tip. However, the potential stripping in HMA or excessive deflection should be considered in the design. Failure in the pavement materials and the compatibility and appropriate use of geosynthetics in pavement systems should not be overlooked.

REFERENCES

Al-Qadi, I. L., Flintsch, G. W., Loulizi, A., Lahouar, S., and Nassar, W. 2001. Pavement instrumentation at the Virginia Smart Road. 14th IRF Road World Congress, Paris, France.

Al-Qadi, I. L., Brandon, T. L., Valentine, R. J., and Smith, T. E. 1994. Laboratory evaluation of geosynthetic reinforced pavement sections. *Transportation Research Record* 1439, Transportation Research Board, Washington, D.C., pp. 25-31.

Al-Qadi, I. L., Brandon, T. L., Bhutta, S. A., and Appea, A. K. 1998. *Geosynthetics effectiveness in flexible secondary road pavements*. The Charles E. Via. Department of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Barksdale, R. D., Brown, S. F., and Francis, C. 1989. *Potential benefits of geosynthetics in flexible pavement systems.* National Cooperative Highway Research Program, Report No. 315, Transportation Research Board, Washington, D.C.

Carroll, R. G., Walls, J. C., and Haas, R. 1987. Granular base reinforcement of flexible pavements using geogrids. *Proceedings of Geosynthetics '87*, New Orleans, LA, 46-57.

Christopher, B. R. and Holtz, R. D. 1991. Geotextiles for subgrade stabilization in permanent roads and highways. Proceedings, Geosynthetics '91, IFAI, St. Paul, MN.

Elseifi, M.A., Al-Qadi, I.L., Loulizi, A., and Wilkes, J. 2001. Performance of a geocomposite membrane as a pavement moisture barrier. Paper No. 01-2660 presented and accepted for publication to transportation research board 80th annual meeting, National Research Council, Washington, D.C.

FHWA. 1993. Guidelines for design, specification, and contracting of geosynthetic mechanically stabilized earth slopes on firm foundations, US DOT, FHWA-SA-93025, Washington, D.C.

Giroud, J. P. and Noiray, L. 1981. Geotextile-Reinforced unpaved road design. Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT 9, pp. 1233-1254. and Discussion: Vol. 108, No. GT 12, pp. 1654-1670.

Giroud, J. P. and Bonaparte, R. 1984. Design of unpaved roads in trafficked areas with geogrids. Proceedings, Symposium on Polymer Grid Reinforcement, ICE, London, UK.

Forsyth, R. A., G. K. Wells, and J. H. Woodstrom. 1987. Economic impact of pavement subsurface drainage. Transportation Research Record, No.1121, Transportation Research Board, Washington, DC, pp. 77-85.

Hass, R. 1987. *Design guideline for flexible pavements with tensar geogrid reinforced base layer*, Tensar Technical Note, Tensar Design Guide (TDG), The Tensar Corporation, Morrow, GA.

Hass, R., Walls, J. and Carroll, R.G. 1988. Geogrid reinforcement of granular bases in flexible pavements, Transportation Research Record, No. 1188, Washington, D.C.

Holtz, R. D. and Sivakugan. 1987. Design charts for roads with geotextiles. Geotextiles and Geomembranes Vol. 5, No. 3, pp. 191-199.

Jorenby, B. N. and Hicks, R G. 1986. Base course contamination limits. Transportation Research Record, No. 1095, Washington, D.C.

Kennepohl, G., Kamel N., Walls, J., and Hass, R 1985. Geogrid reinforcement of flexible pavements: design basis and field trials. Proceedings, Annual Meeting of the Association of Asphalt Paving Technologists, Vol. 54, San Antonio, TX.

Liddle, W. J. 1962. Application of AASHO road test results to the design of flexible pavement structures. Proceedings of the International Conference on the Structure Design of Asphalt Pavements, University of Michigan, Ann Arbor, MI.

Sellmeijer, J. B. 1990. Design of geotextile reinforced paved roads and parking areas. Proceedings, Fourth International Conference on Geotextiles, Geomembranes and Related Products, Vol. 1, Hague, Netherlands, pp. 177-182.

Smith, T. E. 1994. *Laboratory behavior of geogrid and geotextile reinforced flexible pavement.* Masters Thesis, The Charles E. Via. Department of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Steward, J., Williamson, R. and Nohney, J. 1997. Guidelines for use of fabrics in construction and maintenance of low volume roads, USDA, Forest Service, Portland, OR.

Webster, S. L. 1991. *Geogrid reinforced base courses for flexible pavements for light aircraft*, Report No. GL-93-6, Department of the Army, US WES, Vicksburg, MS.