EVALUATION OF GEOSYNTHETIC APPLIED TO FLEXIBLE PAVEMENTS

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Abstract: A computer simulation program was carried out to investigate the effect of utilizing geosynthetics on flexible pavements. A case study was also conducted to compare with analytical results. In order to determine the suitable position of geosynthetics placed in a pavement structure, three locations were considered: (1) at the bottom of subgrade, (2) in the middle of base course, and (3) at the bottom of surface course. It was found that geosynthetic could best prevent pavement cracking and rutting when placed at the bottom of surface course. The use of geosynthetic was shown to prolong pavement life. With savings in materials and in repairs to pavement distresses, the inclusion of geosynthetic could be cost effective. Furthermore, a test section with geosynthetic reinforced, under traffic loading, indicated that the use of geosynthetic improved the resistance of cracking and rutting on flexible pavements.

Key Words: geosynthetic, mechanistic response, pavement performance, test section

1. INTRODUCTION

Conventional flexible pavements are layered with better materials on top where the stress intensity is high, and inferior materials at the bottom where the intensity is low. From top to bottom, they generally consist of surface course, base course and subgrade. Surface course, usually dense graded asphalt concrete (AC), is designed to resist traffic load, and to be waterproof to prevent water from getting into whole pavements. Base course generally constructed by crush stones is used to distribute stress down to roadbed. Subgrade built on natural roadbed needs to compact to desirable density near the optimum moisture content. Since the asphalt concretes are the predominant materials used in flexible pavements, asphalt pavements and flexible pavements are interchangeable for engineering purposes.

Distresses on flexible pavements include cracking, surface deformation, disintegration, and surface defect. The former two failures are related to the pavement structure, while the rest more pertains to the properties of asphalt mixtures. The construction of paved and unpaved roads over low bearing capacity soils has proved to be a problem to engineers for centuries. Over the last twenty years the construction industry has seen the rapid development of geosynthetics used in all aspects of Civil Engineering applications but especially in pavement construction. Introducing geosynthetics into road construction contains potential benefits of improving pavement distresses. A significant part of their application can be due to the strengthening effects they can impart on a pavement structure.

Research is still conducted on determining the best possible location for the geosynthetic strengthening.(Haas *et al.* 1988; Chan *et al.* 1989; Miura *et al.* 1990; Moghaddas-Nejad *et al.* 1996) The arguments are ongoing among those who prefer to install it between base course and subgrade, and those who want to place it higher up in the pavement structure, say, on the bottom of the surface course. Furthermore, it is arguable that geosynthetic serves pavements better than ones without it for a long run. Even if geosynthetic does help alleviate pavement distresses, the benefits of improving pavement performance may not justify the costs of installing it.

This paper is to compare the stress and strain within the pavement structures that are with and without reinforcement. Different geosynthetic positions will be evaluated based upon loading mechanism and pavement performance in the long run. Pavement performance with reinforcement will be compared with one without reinforcement. Test sections were also installed with geosynthetic to evaluate its performance under traffic loading.

2. PAVEMENT ANALYSIS

Flexible pavements can be characterized as a multi-layered elastic system, i.e., surface course, base course and subgrade. Two specific stress-strain conditions are considered, as shown in Figure 1. In Figure 1, the traffic weight, W, is loaded to the pavement surface through the tire as an approximately uniform vertical pressure, p_0. The pavement structure then spreads the load stresses, thus reducing their intensity until, at the surface of the subgrade, the vertical pressure has a maximum intensity of p_1. Because of the pavement structure, the maximum vertical pressure intensity decreases with depth, from p_0 to p_1. The second condition as illustrated by the figure in the right hand shows that the wheel load, W, deflects the pavement structure and causes both tensile and compressive stresses and strains in the asphalt layer.

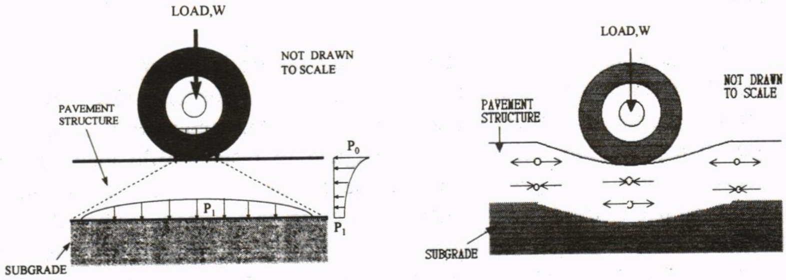

Figure 1. Pavement Stresses in Pavement Structure

The intent of the pavement analysis is to simulate, in advance, the expected performance of the asphalt pavement so that the pavement responses of the various layers can be optmized and the available materials can be used effectively. Thus, it is possible for an engineer to use the information of the type presented and, interacting with a computer work station, to carry out for either new or rehabilitated pavements designs that range from relatively simple to complex, depending on the significance (and cost) of the particular project.

A number of computer programs based on the multi-layered elasticity (MLE) or the finite-element (FE) method have been developed and used for structural analysis of flexible pavement.(Monismith 1994) The use of multi-layered analysis to calculate pavement response was first developed by Burmister in the 1940s. Although some agencies utilized solutions for two- and three-layered elastic solids in their design methodologies, the use of these solutions was both limited and cumbersome at that time. However, important contributions were made by Dormon, Skok and Finn, and Peattie. They illustrated how layered-elastic analysis could be used to analyze pavement distress. These general solutions, coupled with the rapidly advancing computer technology, advance the development of the current generation of multi-layer elastic and viscoelastic computer programs. Overall, the MLE-based procedures are used because of their simplicity, but they may suffer from the inability to evaluate the stress-dependant behavior of soil and granular materials and may yield tensile stresses in granular material, which do not occur in the field.(Chen, Bhatti 1997)

In the late 1960s finite-element analyses to represent pavement response were developed by researchers such as Duncan *et al.* Increasingly the finite-element method has been used to model pavement response, particularly to describe the nonlinear aspects of materials behavior. The significant work of various researchers illustrated how the nonlinear response of granular materials should be reasonably accounted for in pavement analyses.(Zaman *et al.* 1994; Chen *et al.* 1995) Current finite-element methodology has some advantages over layered-elastic and viscoelastic solutions because it provides greater flexibility in realistically modeling the nonlinear response characteristics of all the materials that make up the pavement section.

3. COMPUTER SIMULATION

In this study, the pavement system is considered a three-layer system, including the subgrade, granular base, and surface asphalt concrete. This consideration corresponds to pavement sections tested later. A comprehensive analysis of flexible pavements should include the stress-dependant behavior of granular base course and the cohesive subgrade, the geostatic force of the pavement itself (gravity load), finite width of the AC pavement, multiple wheel loading at any location of the given domain being analyzed, and bonding capacity between the AC and the granular layer. Although a number of structural analysis programs based on either FE or MLE methods are available, none of these computer programs is capable of incorporating all these parameters in analysis simultaneously. Selection of an appropriate computer program for structural analysis of flexible pavements is a challenge for the pavement engineers.

4. MICH-PAVE COMPUTER PROGRAM

According to recent studies, MICH-PAVE, a FE computer program appears to be one of best computer programs to predict pavement responses and performance. This program has been widely used by pavement researchers.(Chen *et al.* 1995; Monismith 1994) The stress-dependant properties in the form of resilient modulus (M_R) and the failure criteria for granular materials and fine-grained soils are incorporated. The principal stresses in the granular and subgrade layers are modified at the end of each iteration in a way whereby they do not exceed the strength of the materials. MICH-PAVE uses the Mohr-Coulomb failure criterion to characterize granular materials and fine-grained soils and to adjust the state of stresses. MICH-PAVE assumes a flexible boundary at a limited depth beneath the subgrade instead of a rigid boundary at a greater depth (50 times the radius of the applied load) below the subgrade.

The flexible boundary, which accounts for displacements that occur beneath it, enables the bottom boundary to be placed at any depth below which displacements and stresses are of no interest. The use of the flexible boundary greatly reduces the number of degrees of freedom (DOF) required and thus reduces the computation time. The half-space below the flexible boundary is assumed to be homogeneous and linear elastic. To account for the coupling between the flexible boundary and the finite elements, the stiffness matrix of the half-space, which corresponds to the DOF along the boundary, is obtained from the inverse of the flexibility matrix because of its simplicity.

4.1 Nonlinear Analysis in MICH-PAVE

To determine the stresses, strains, and deflections in the pavement system, it is necessary to have a proper constitutive model to address the stress-dependant behavior of granular materials and the subgrade soils. The stress-dependant characteristics of untreated granular materials in Equation 1 are most commonly used by researchers (Zaman *et al.* 1994; Chen *et al.* 1995), and it is used in MICH-PAVE.

$$M_R = K_1 \cdot \sigma_3^{K_2} \quad \text{OR} \quad M_R = K_1' \cdot \theta^{K_2'} \qquad (1)$$

where,

σ_3 = confining pressure
θ = stress invariant = $\sigma_d + 3\sigma_3$ (for triaxial test)
K_1 , K_2 , K_1' , K_2' = constants

K_1 , K_2 , K_1' , and K_2' are material constants determined from laboratory testing. The ranges of these constants are well documented.(AASHTO 1991; Zaman *et al.* 1994; Chen *et al.* 1995) For a cohesive subgrade soil, the M_R is expressed through a bilinear relationship, as given in Equations 2 and 3.

$$M_R = K_2 + K_4 \, . \, [(\sigma_1 - \sigma_3) - K_1] \qquad \text{for } K_1 < (\sigma_1 - \sigma_3) \qquad (2)$$
$$M_R = K_2 + K_3 \, . \, [K_1 - (\sigma_1 - \sigma_3)] \qquad \text{for } K_1 > (\sigma_1 - \sigma_3) \qquad (3)$$

in which K_1, K_2, K_3, and K_4 are material constants.

5. CASE STUDY - I

The material properties used in this study are shown in Figure 2. In order to determine the best possible location for the geosynthetic strengthening, four circumstances are analyzed in this study: (a) unreinforced, i.e., pavements without geosynthetic reinforcement, (b)on the top of base, (c) in the middle of base and (d) on the top of subgrade. Data presented for case study are typical situations that are commonly encountered in the Southeast Asia.

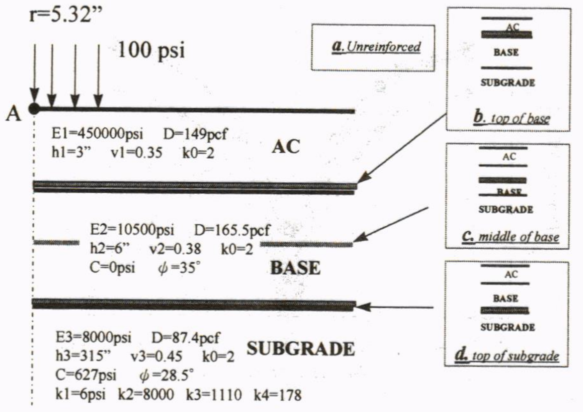

Figure 2. Material Properties and Four Geosynthetic Locations Analyzed in This Study

5.1 Results and Discussions

The results of introducing geosynthethics are presented by Figures 3 to 5, for tensile stresses, tensile strains and deflections, respectively. Pavements with geosynthetics are shown to have advantages over ones without reinforcement in terms of less pavement responses. Each situation is discussed as follows.

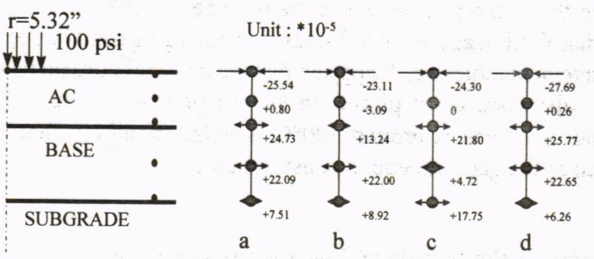

Figure 3. Comparison of Tensile Strains for Various Geosynthetic Locations

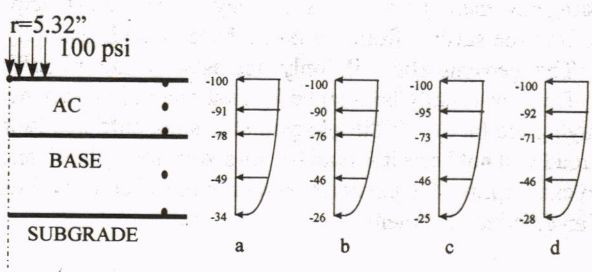

Figure 4. Comparison of Tensile Stresses for Various Geosynthetic Locations

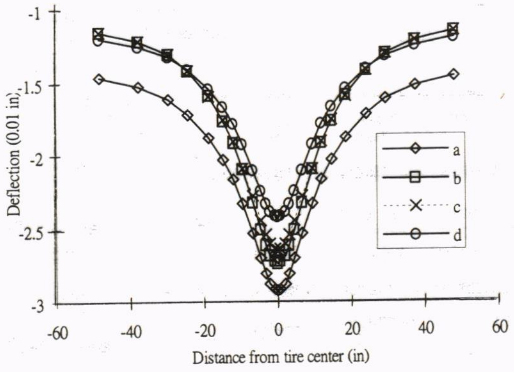

Figure 5. Comparison of Pavement Surface Deflection for Various Geosynthetic Locations

5.2 Geosynthetic Placed on the Top of Base Course - situation b

When the geosynthetic is placed on the top of base course it serves as a reinforcement for both preventing tensile cracking and reducing rutting. Figure 3 shows that the tensile strain at the bottom of asphalt concrete is the least for situation b if there is good bondage among asphalt concrete, geosynthetic and base course. Pavement surface deflection as shown in Figure 5 is also shown a similar trend, indicating that the geosynthetic may act as a strain/deflection absorber as to reduce the strain and deflection transformed to the surface and base courses. However, the stress distribution as shown in Figure 4 is not significantly affected by adding the geosynthetic to the pavement structure. It appears that the geosynthetic can be most effective on preventing pavement distresses when placed on the top of base course. Since the laydown temperature of asphalt mixtures is around 100°C, special attentions should be paid to the temperature resistance of the geosynthetic in construction sites.

5.3 Geosynthetic Placed in the Middle of Base Course - situation c

If the geosynthetic is placed in the middle of base course (or is used with thin layer overlays as a repair method on existing pavements) it performs two ways. Firstly it can help to prevent cracks working their way up into the surface from the layers beneath and, secondly, it can act as an impermeable barrier. The geosynthetic will only act as a barrier if sufficient binder has permeated the fabric. This can usually be assured by first applying a tack coat to the existing road surface before laying the fabric. If the geosynthetic is not sufficiently impregnated, then the service life of the road will not be as it should be. As shown in Figures 3 and 5, geosynthetics placed at this position can improve the pavement response of either a new highway or improve the characteristics of an existing pavement.

5.4 Geosynthetic Placed on the Top of Subgrade - situation d

If the geosynthetic is placed on the top of subgrade, it does help to reduce the contamination of the base by fines migrating from the subgrade. Without the geosynthetic layer the effective base thickness may be reduced by intermixing with subgrade fine soil under the action of wheel load. Another advantage of this positioning is that, provided there is a good bond between the fill and the upper surface of the geosynthetic, it will absorb part or all of the outwards horizontal shear stress which would otherwise be transmitted from the surface layer to the subgrade. By absorbing this shear stress the geosynthetic increases the vertical load that can be applied to the formation before substantial vertical deformation occurs. However, the reduction on pavement responses at this position is relatively small as compared to the two previous situations as shown in Figures 3 and 5. In addition, despite the best efforts of the manufacturers, a geosynthetic material strong enough and stiff enough to provide adequate support for the weight of a thick pavement construction has yet to be found. This has meant that the better position for a geosynthetic barrier can be on the top of base course.

5.5 Pavement Life Improvement

Considering the preliminary analysis results in Table 1, pavement service lives in terms of strains, equivalent single axle load (ESAL) and rutting are extended after the geosynthetic is introduced into the pavement structure. One of the most significant improvement is the increase in ESAL, inferring that pavements with a geosynthetic placed on the top of base course can last trafficking ten times longer than plain pavements. Since introducing the geosynthetic is shown to improve pavement life, it is cost effective if the geosynthetic can be properly placed into the pavement structure.

Table 1. Pavement Life Prediction for Four Situations

	a	b	c	d
Maximum tensile strain in the asphalt layer (%)	2.473E-04	1.324E-04	2.180E-04	2.577E-04
Average compressive strain in the asphalt layer (%)	1.288E-04	1.173E-04	1.250E-04	1.218E-04
Maximum compressive strain at top of subgrade (%)	1.454E-04	1.155E-04	3.224E-04	3.301E-04
Fatigue life of asphalt pavement (ESAL)	6.660E+05	5.041E+06	2.112E+06	1.395E+06
Total expected rut depth of the pavement (in)	2.748E-01	2.992E-02	6.850E-02	3.304E-01
Expected rut depth in the asphalt course (in)	4.112E-02	2.010E-03	4.827E-02	5.415E-02
Expected rut depth in the roadbed soil (in)	1.952E-01	2.069E-01	8.461E-03	9.169E-03

6. CASE STUDY - II

For this research design input data for pavement design is obtained for the conditions of national highways in Taiwan. These include roadbed strength, traffic, asphalt concrete (AC) and unbound material characteristics, reliability and standard deviations. The drainage conditions are considered in good ability. Table 2 lists the material properties used. By using the design charts provided in the AASHTO Guide for Design of Pavement Structures 1993, pavement thickness obtained for the three cases is given in Table 3.

Table 2. Pavement Design Input Data

Case No.	CBR	Layer Resilient Modulus (M_R) (MPa)				ESAL (Million)	Reliability (%)	Standard Deviation
		AC	Base	Sub-base	Subgrade			
1	3	3104	207	103	31.0	12.76	90	0.45
2	5	3104	207	103	52.0	17.48	90	0.45
3	8	3104	207	103	83.0	26.42	90	0.45

Table 3. Pavement Thickness

Case No.	S_N	Total Thickness (mm)	Layer Thickness (mm)		
			AC	Base	Subbase
1	6.0	762	203	127	432
2	5.5	635	203	178	254
3	5.0	483	254	127	102

6.1 Comparison of Pavement Designs Without and With Geosynthetic

Rutting

Deflection and vertical strain at top of subgrade is significant for rutting failure in a pavement. Figures 6 and 7 show the comparison of these mechanistic responses for design without and with inserting geosynthetic membrane under asphalt concrete layer. The above figures show that both the responses are comparatively decreased when geosynthetic membrane is inserted under the asphalt concrete layer. This effect is also true for the analysis made for 9.982- and 11.796-ton wheel loads. It is obvious from the result of analysis that the pavement resistance is improved against rutting by inserting the geosynthetic membrane under the asphalt layer.

Vertical compressive stress at top of roadbed contributes to permanent deformation in a pavement structure. Figures 8 and 9 indicate the vertical compressive stress at top of subgrade for different wheel loads. Results show that this stress is considerably lowered by incorporating geosynthetic membrane under asphalt concrete layer. This confirms that geosynthetic layer helps in absorbing the stresses and strains coming on pavement structure. With its incorporation in pavement the stresses are distributed over a larger area, thus lowering stresses at critical points. It is believed that the geosynthetic plays an important role in two mechanisms that reduce the permanent deformation of the pavement. The geosynthetic is a significant reduction in the deformation of the subgrade due to the confinement and interlocking of the subgrade materials, and the improved load distribution on the subgrade layer.

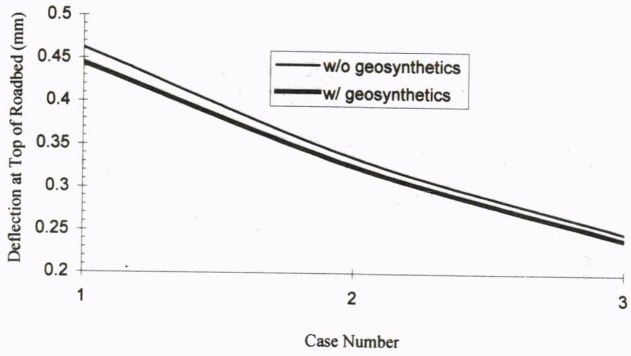

Figure 6. Deflection at Top of Roadbed Using 8.167-ton Wheel Load

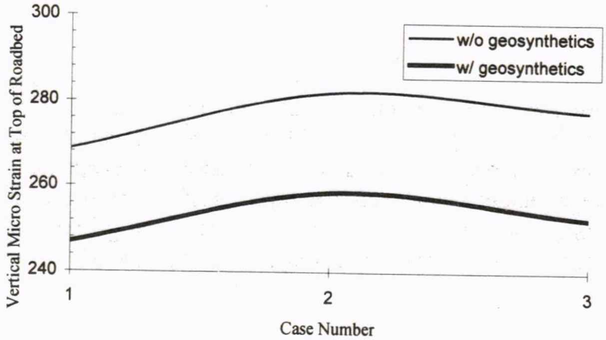

Figure 7. Vertical Strain at Top of Roadbed Using 8.167-ton Wheel Load

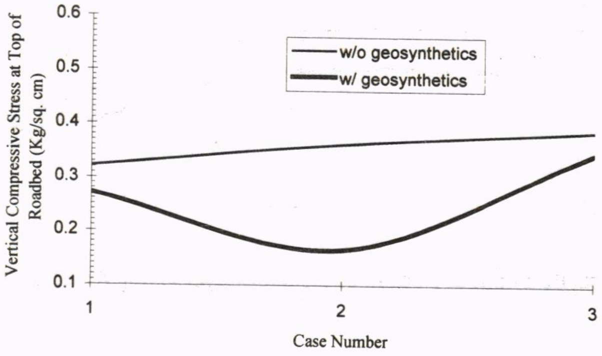

Figure 8. Vertical Compressive Stress at Top of Roadbed Using 9.982-ton Wheel Load

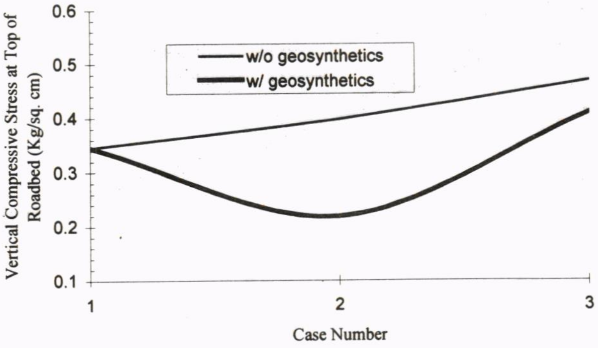

Figure 9. Vertical Compressive Stress At Top of Roadbed Using 11.796-ton Wheel Load

Fatigue Failure

Mechanistic response associated with fatigue failure in a pavement structure is the tensile strain at bottom of asphalt layer. Figures 10 and 11 show the comparison of strains coming on pavement structures designed with and without using geosynthetic. By insertion of geosynthetic membrane under asphalt concrete layer tensile micro strain under asphalt layer is decreased by approximately thirty percent. This indicates that geosynthetic in addition with base layer releases more tension under asphalt layer as compared to base alone.

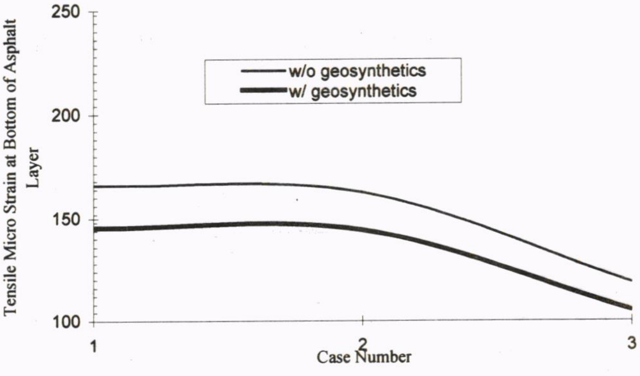

Figure 10. Tensile Strain at Bottom of Asphalt Layer Using 8.167-ton Wheel Load

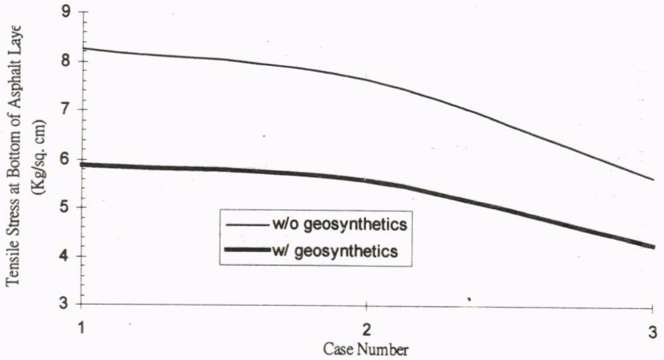

Figure 11. Tensile Stress at Bottom of Asphalt Layer Using 9.982-ton Wheel Load

Thermal Cracking

Thermal cracks are initiated by tensile stress produced under asphalt layer at low temperatures when the asphalt layer is comparatively stiff. For this case, analysis indicates that inserting geosynthetic membrane under asphalt layer in a pavement structure reduces the tensile stress by approximately thirty-five percent as shown in Figures 12 and 13. Hence the structure with geosynthetic membrane will be safer against thermal cracks as opposed to the structure without geosynthetic. It is thus found out that geosynthetics can be very helpful in controlling stresses and strains in a pavement structure.

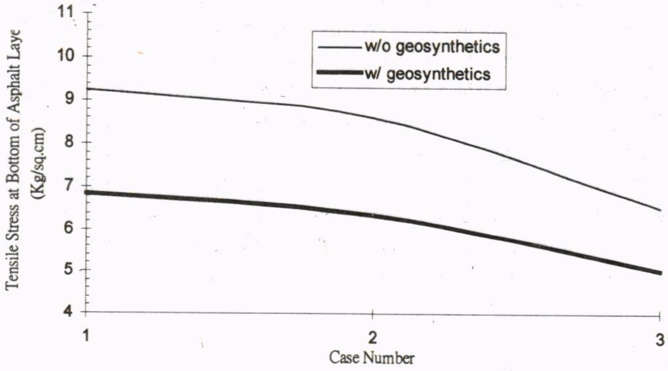

Figure 12. Tensile Stress at Bottom of Asphalt Layer Using 9.982-ton Wheel Load

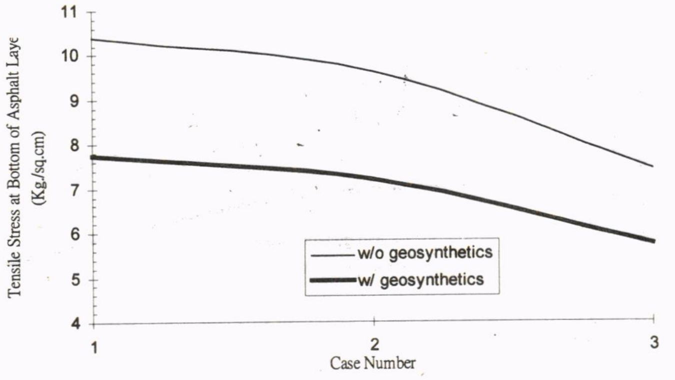

Figure 13. Tensile Stress at Bottom of Asphalt Layer Using 11.796-ton Wheel Load

7. GEOSYNTHETIC PERFORMANCE IN PAVEMENTS

Geosynthetic reinforcement has been mechanistically established previously. It is necessary to verify the performance of geosynthetics in highway construction. For further actual validation of geosynthetic application, experiments in laboratory and observations in field are presented respectively here.

7.1 Fatigue Test Results in Laboratory

The dynamic fatigue test system including a loading system, a measurement system, a temperature control system and a rubber-made elastic foundation was performed. The purpose of test is to evaluate the resistance of reinforced asphalt concrete beams to pavement performance. A series of testing for a beam reinforced with geosynthetic membrane of 200 kN/m strength showed a fatigue life 5 to 9 times that of the non-reinforced beam longer under the same level of loading, as shown in Figure 14. Because of the extremely high level of loading used in this test, the lower strength non-reinforced beam (AC-20) breaks during the process of loading, and, therefore, its effectiveness in enhancing fatigue life is rather limited. In other words, the higher strength geosynthetic reinforced beam exhibits a much better reinforcement as it would not break during the loading process and produces satisfactory performance. Similar Results are also reported by other researchers.(Chang *et al.* 1998)

7.2 Observation Results in Field

The UK transport Research Laboratory (TRL) conducted a full scale trafficking trials both in a test facility and in the field.(Tensar Corporation 1987) Figure 15 summarises the results of the tests in field. It was found that, when geosynthetics was used, a given sub-base thickness could carry about 3.5 times more traffic. The result, of which Figure 15 is typical, showed that a reduction in rut depth of 50 percent was achieved, indicated that the geosynthetic reinforcing structure is a factor contributing to the effectiveness of soil bearing capacity improvement.

Furthermore, it was also found to be not the geosynthetic membrane effect, but an aggregate confinement effect that limits tensile strains in the subgrade and hence preserves the sub-base/subgrade interface. This is a vital performance indicator to validate the control of deformation (rut depth) and the preservation of the subgrade/sub-base interface. In other words, using the geosynthetic structure can reinforce the resistance of rutting and cracking on flexible pavements.

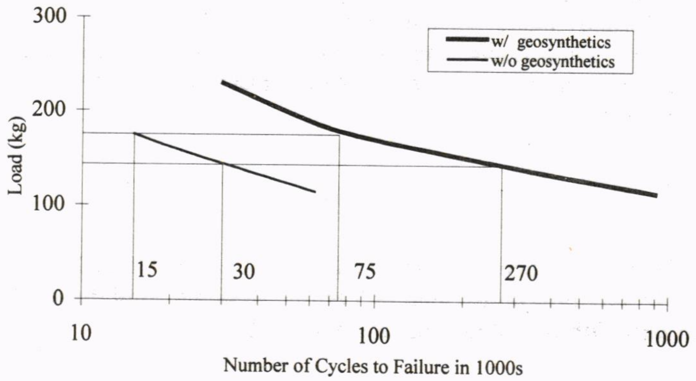

Figure 14. Effect of Geosynthetic Reinforced Asphalt Sample

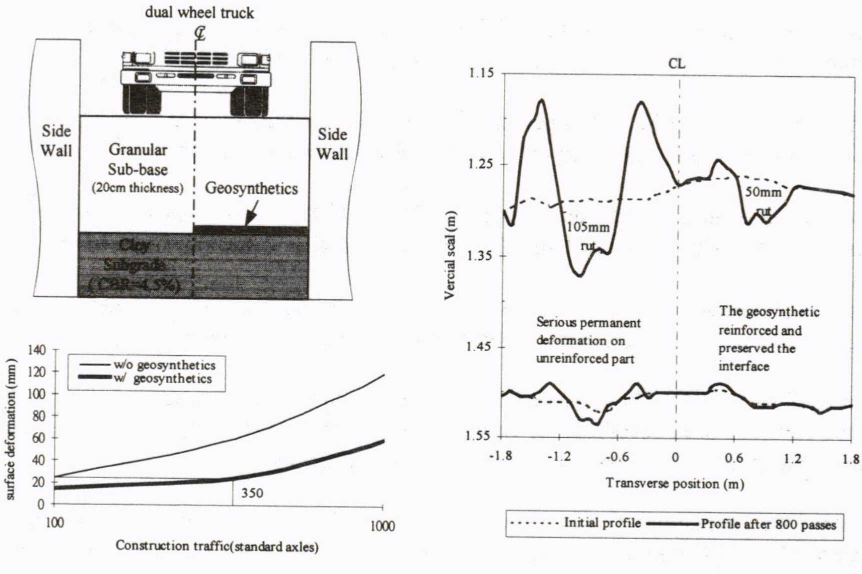

Figure 15. Summary of Geosynthetic Reinforcing Structure and Performance in Field

8. CONCLUSIONS AND RECOMMENDATIONS

Comprehensive evaluation of geosynthetic locations is carried out by a computer program called MICH-PAVE. Selection of MICH-PAVE is based upon its versatile and proven abilities on simulating pavement performance. Pavements with geosynthetics placed on the top of base course are found to perform better than ones with geosynthetics placed at other locations. The inclusion of geosynthetics is shown to have following advantages: (1) cracking reduction, (2) less deformation of the pavement, and (3) reduced pavement thickness. These benefits are magnified if pavements have to bear heavy traffics. Because of these effects, pavement life is shown to be significantly improved; thus, it can be cost effective to use geosynthetic in a pavement structure. Furthermore, incorporating geosynthetics under asphalt layer in a pavement system may be able to reduce base/subbase thickness in areas where these materials are comparatively expensive.

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