

GEOSYNTHETIC-REINFORCED PAVEMENT SYSTEM : TESTING & DESIGN

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ABSTRACT

A large scale experimental program was presented in this paper, aimed at the improvement of the understanding, and evaluation of the structural contribution of geosynthetic reinforcement to pavement systems. The structural contribution of a geogrid was quantified by the increase in the layer coefficient of the base course material. Design parameters derived from the laboratory testing were analyzed and presented. A design method for geosynthetic reinforced pavement system was developed. A design example and design charts are provided. A cost benefit analysis is also conducted.

INTRODUCTION

Geosynthetics, as applied to flexible pavement systems, have been widely used in recent years. The benefits of geosynthetics in flexible pavement systems were presented by Barksdale, et al. (1989). Geosynthetic reinforcement is typically placed in the interface between the aggregate base course and the subgrade. Although many projects of this kind have been successfully installed, there is still a lack of understanding about the behaviour of the composite system, especially rigorously quantifying the structural contribution by geosynthetic reinforcement and incorporating it into a design methodology.

A large scale experimental program was presented in this paper, aimed at the improvement of the understanding, and evaluation of the structural contribution of a geogrid to pavement systems. Laboratory tests were performed to study flexible pavement systems under simulated traffic loading conditions. Asphalt layer, aggregate base course and subgrade soil were included in the pavement sections. Pavement sections with different subgrade strength were tested.

Number of dynamic loading cycles along with the pavement deformation were recorded. Flexible pavement testing with different geosynthetic reinforcement was conducted in conjunction with University of Milan as reported by Cancelli et al. (1996).

Existing design methods for flexible pavements include empirical methods, limiting shear failure methods, limiting deflection methods, regression methods, and mechanistic-empirical methods. AASHTO method is a regression method based on the results of road tests. AASHTO published the interim guide for design of pavement structures in 1972, a revised version in 1981. Reliability concept is used in the current AASHTO design method, however, design method in accordance with the interim guide are still being used due to its simplicity and familiarity to design engineers. In this paper, design parameters derived from the laboratory testing were analyzed and presented. A modified AASHTO design method (based on the interim guide) for geosynthetic reinforced pavement system, capable of determining the required aggregate thickness (when the asphalt thickness is given) or the required asphalt thickness (when the aggregate thickness is given), was developed. The structural contribution of a geogrid reinforcement on flexible pavements is quantified by the increase in the structural layer coefficient of the aggregate base course. A design example and design charts are provided. Cost benefit analysis is also presented.

TESTING PROGRAM

The typical cross-section of testing set-up is shown in Figure 1. A geosynthetic layer was placed only in one half of the box section, while the other half was left unreinforced to be used for comparison purposes. This technique allows a greater precision in determining reinforcement effects since the properties of the soils in the two halves were the same because the two parts of the box were filled at the same time using the same soil handling procedures. The geogrid reinforcement layer was placed flat above the layer of loose soil and then folded at 90° at the box sides. The geogrid was folded to the metal box sides to model the anchorage effect in a typical wide road base. In this way the pullout failure of geogrid is prevented due to the relatively small dimensions of the testing box. Similar concept was utilized by Gregory and Bang (1994).

Up to 300,000 sinusoidal loading cycles have been applied through a circular loading plate having 300 mm diameter. The tests have been performed at a frequency of either 5 or 10 Hz and the load was ranging from 0 to 40 kN with an equivalent maximum applied pressure of 570 kPa. The vertical settlements (ruts) have been recorded as a function of number of cycles together with the permanent deformation in the road section.

The sinusoidal cycle loading has been applied through a servohydraulic actuator controlled by an Instron 8580 digital multi-axis closed-loop controller and the rut depths were measured by a transducer inside the piston. The settlements and the elastic rebounds of the asphalt layers have been measured during the tests, under the loading plate, every 100 cycles. The distribution of the permanent deformation on the aggregate was recorded during the tests by measuring the

displacements of the asphalt surface in several locations, and of the asphalt/aggregate and aggregate/subgrade interfaces at the end of each test.

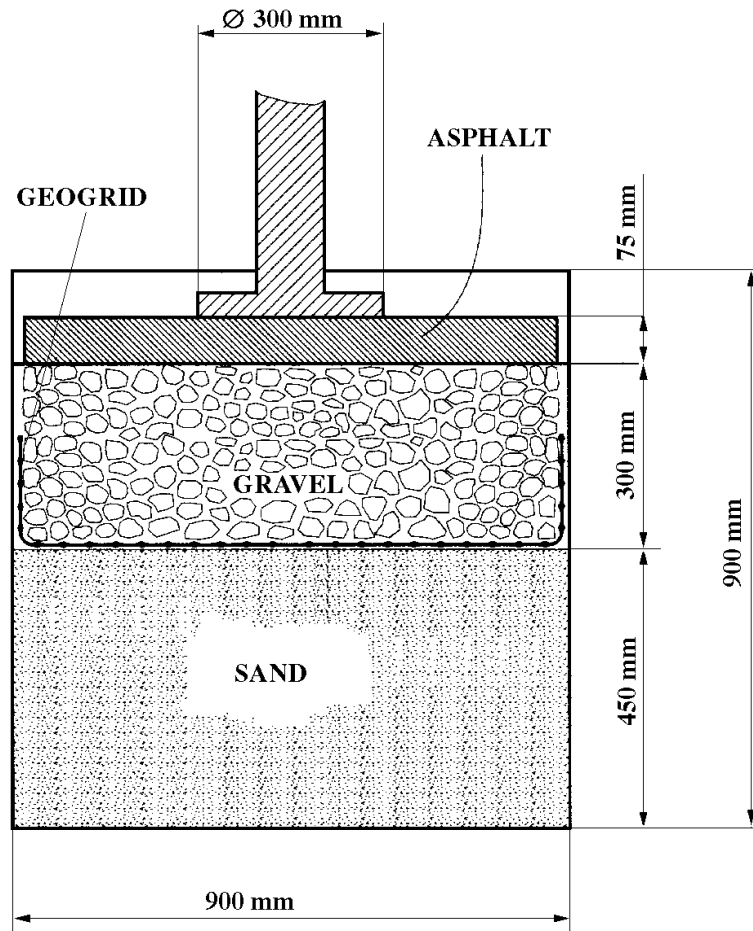


Figure 1. Pavement testing set-up

The thickness of the asphalt layers has been kept constant and equal to 75 mm. The asphalt specifications were in accordance to the Italian highway department requirements. Crushed limestone produced from oversize quarried aggregate was selected as the base course material. This material is typically used for paved roads. The maximum particle size of the aggregate was 30 mm. The gravel aggregate was placed in 300 mm thickness and compacted to achieve a density of about 17.50 kN/m^3 . The soft and compressible subgrade was simulated by means of about 450 mm of loose uniform sand having a uniformity coefficient $U \gg 2$, dry density $\gamma = 19.00 \text{ kN/m}^3$ and an optimum moisture content $w = 15\%$. This sand is called Ticino siliceous sand since it is dredged from the Ticino river. A constant moisture content of 10% for the sand was selected. Several subgrade shear strengths with CBR value ranging from 1% up to 18% (ASTM D1883) have been used in the tests by changing sand density. The gradation curve for asphalt, crushed stone, and the subgrade sand are shown in Figure 2 as per ASTM D136.

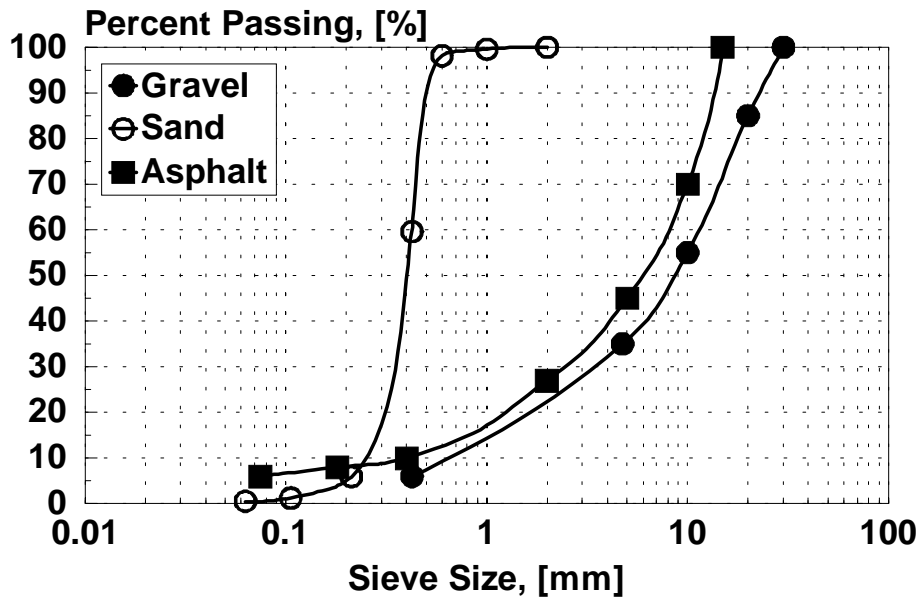


Figure 2. Gradation curves for crushed limestone, sand and asphalt.

A multilayer biaxially oriented polypropylene geogrid, Tenax MS220, manufactured by continuous extrusion and orientation processing is used as reinforcement in the tests. Its main properties are listed in Table 1.

Table 1. Properties of the multilayer geogrid used in the tests

		Machine Direction	Cross Machine Direction
Unit weight	g/m ²	220	
Aperture size	mm	21	25
Peak tensile strength	kN/m	13.5	20.5
Tensile modulus @2% strain	kN/m	205	300
Yield point strain	%	12	11
Junction strength	kN/m	12.2	18.5

TEST RESULTS AND ANALYSIS

Figure 3 shows the comparisons of vertical settlement between reinforced and unreinforced sections. Ruts geometry for reinforced and unreinforced sections have been analyzed to determine differences in depth and shape of the deformed sections.

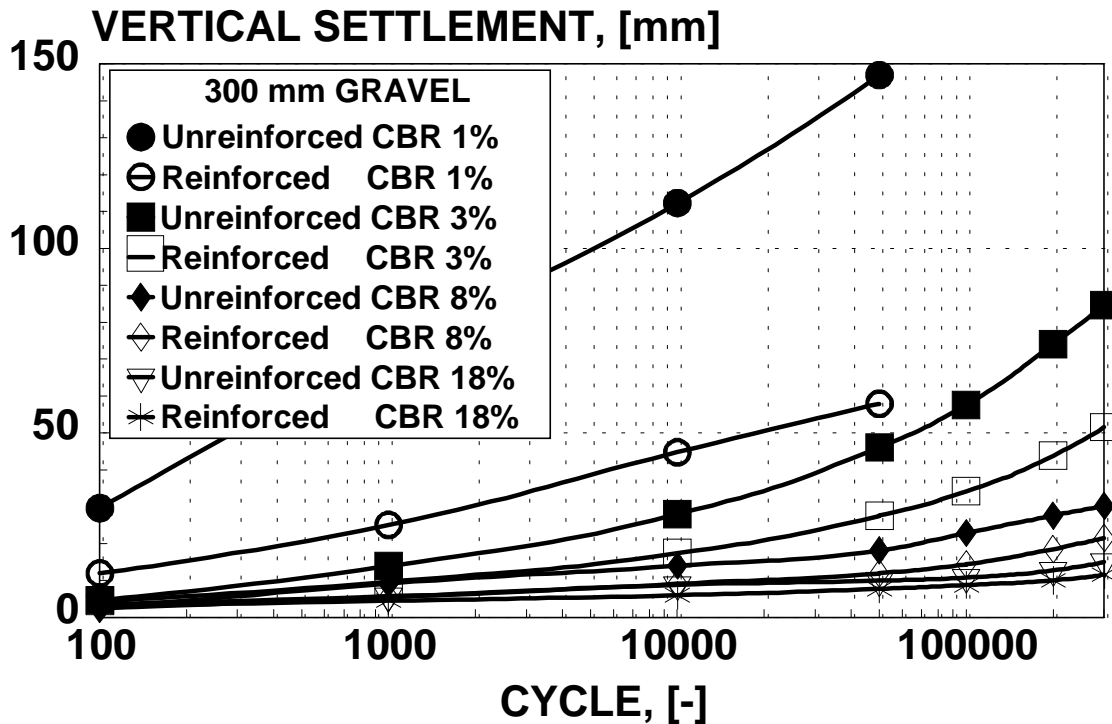


Figure 3. Comparisons between unreinforced and reinforced sections.

Typical permanent rut geometry for CBR =1% and 18% are presented in Figure 4. As it can be noticed by analysing Figure 4, the deformation curves are very sharp in proximity of the loading plate area. In fact, the failure type for all the performed tests has been a puncture failure by shearing the asphalt layer not sufficiently supported by the layer underneath. This type of failure is essentially due to the type of subgrade used during the tests. In fact the soft sand has a very high compressive behaviour and largely reduces its volume when compressed. Moreover the rigid loading plate generated high shear stresses on the asphalt at its edges.

The influence of different aggregate base thickness on the pavement performance is presented in Figure 5. Reinforced section with one layer of geogrid reinforcement performed significantly better than unreinforced sections with thicker base course. Due to the limitation in the depth of the testing box, the unreinforced section with base thickness of 500 mm has only 300 mm thick sand subgrade, which contributed to smaller settlement as shown in the figure.

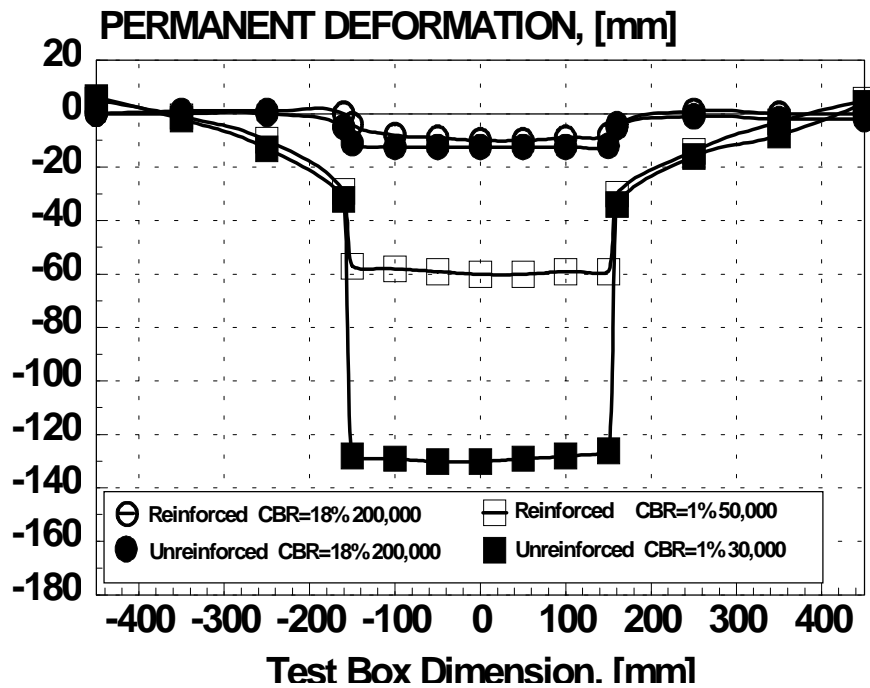


Figure 4. Typical ruts geometry for unreinforced and reinforced sections with different CBR values.

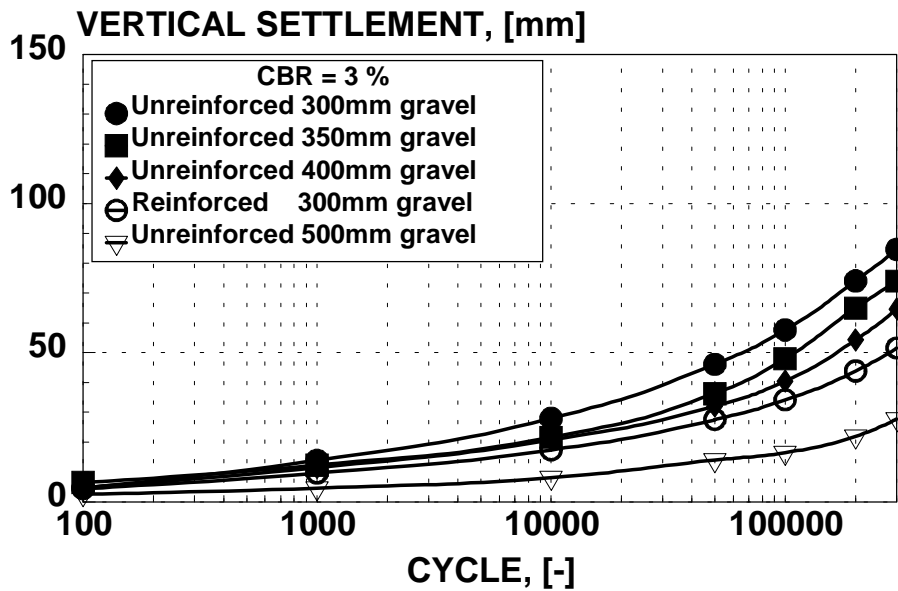


Figure 5. Comparisons between unreinforced and reinforced sections for several base thickness.

The deformed shape of the asphalt - aggregate and aggregate-subgrade interfaces, at the end of a test, are shown in Figure 6 and Figure 7. It is interesting to note that the maximum settlement, both at the asphalt-aggregate and at the aggregate - subgrade interfaces, is much lower for the geogrid reinforced sections than for the unreinforced ones. Figures 6 and 7 also show that 2 layers of geogrids, one at the base and one at the mid thickness of the aggregate layer, are able to provide more stiffening to the base layer than 1 geogrid only: in fact with 2 geogrids, the deformation is much more uniform and the maximum settlement is lower.

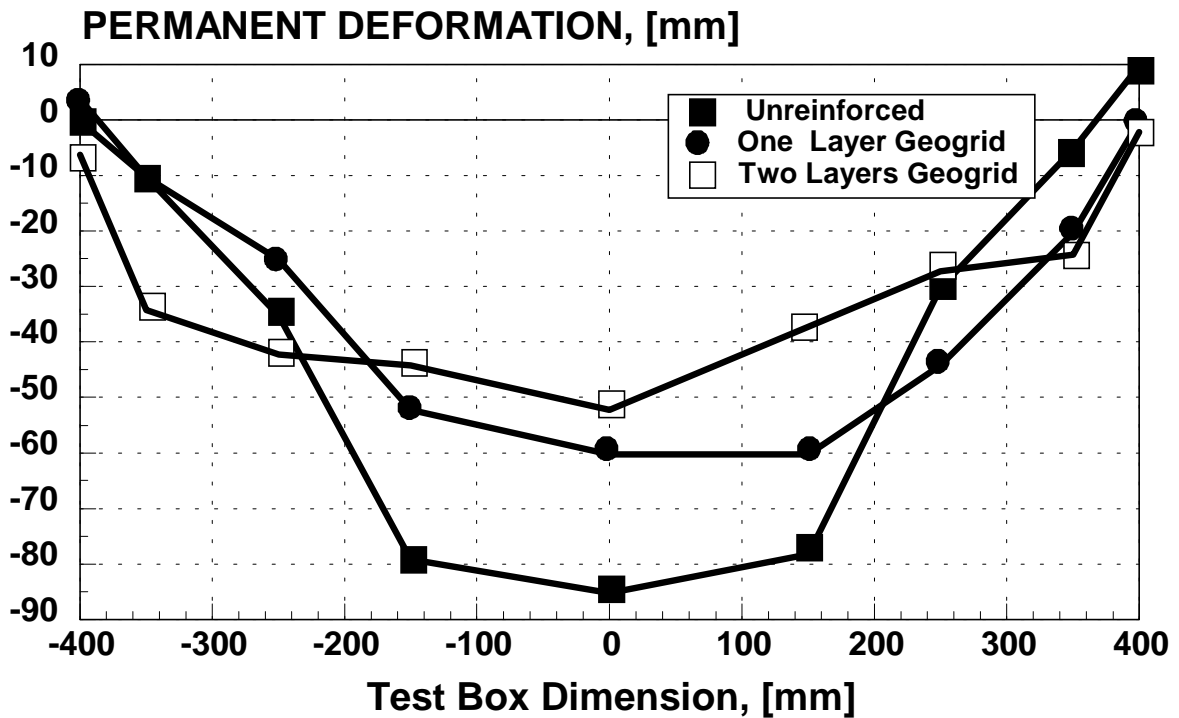


Figure 6. Typical deformed shape of the asphalt-aggregate interface at the end of a test.

Function of the subgrade CBR versus number of cycles is presented in Figure 8 based upon data presented in Figure 3. Figure 9 shows the traffic improvement factor (the ratio of the number of load cycles for the reinforced section to that of unreinforced section at a given rut depth). Figure 9 is simply obtained from the ratios of the related points in Figure 8. The chart in Figure 8 allows to evaluate the increase of design life (in terms of increased number of vehicles passing) which can be achieved by placing a geogrid in a given road section. As indicated in Figure 8, the structural contribution of a geogrid reinforcement is nearly constant when the subgrade CBR value larger than 3% for both 12.5 mm and 25 mm rut depth; while for relatively weak subgrade with CBR value equal to 1%, the structural contribution of a geogrid under 25 mm rut depth is significantly larger than rut depth of 12.5 mm.

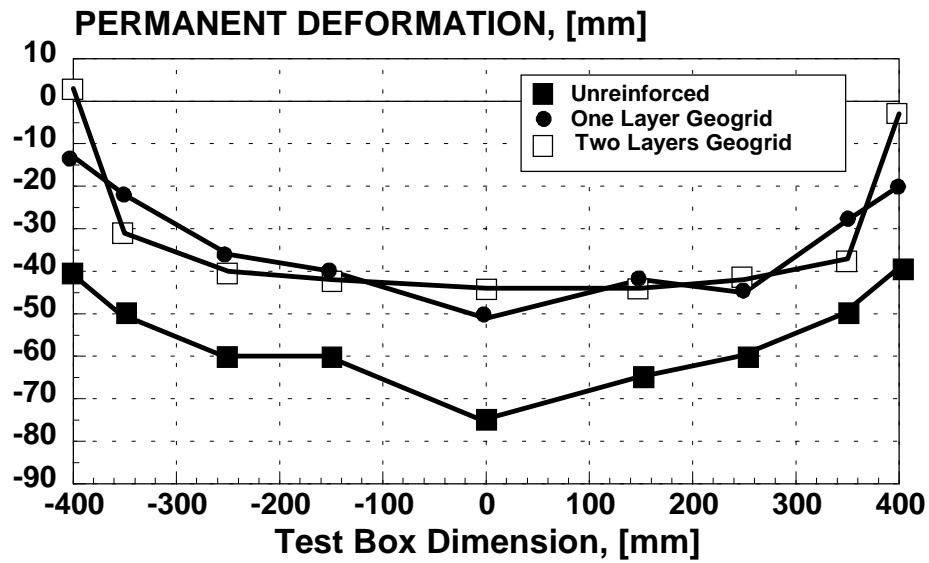


Figure 7. Typical deformed shape of the aggregate-subgrade interface at the end of a test.

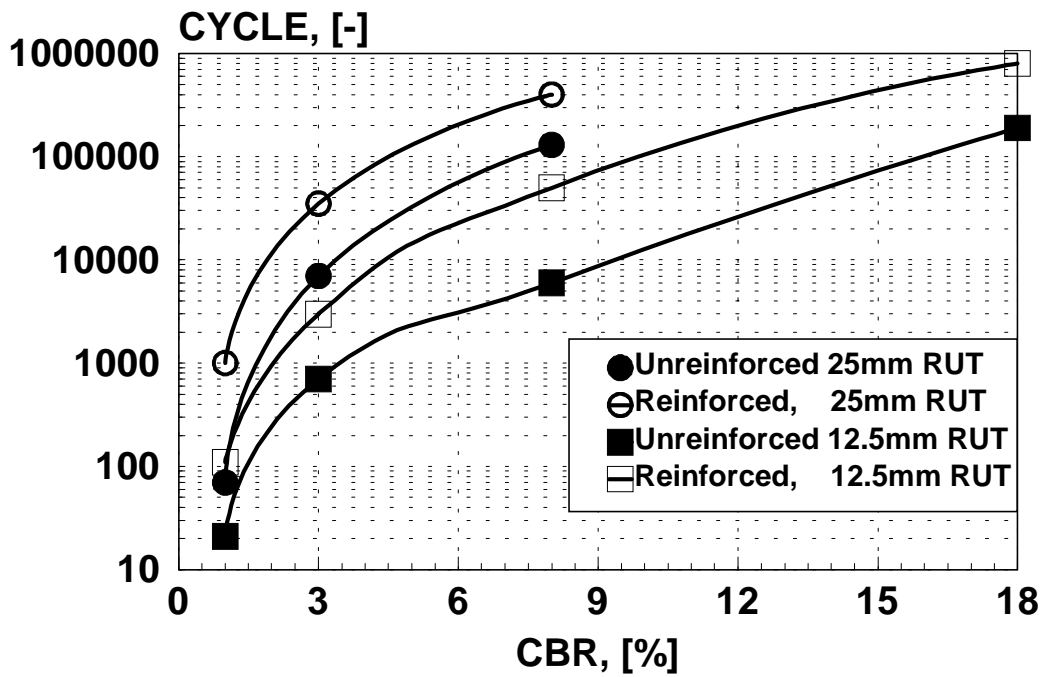


Figure 8. CBR vs. cycle number for reinforced and unreinforced sections at given rut depth.

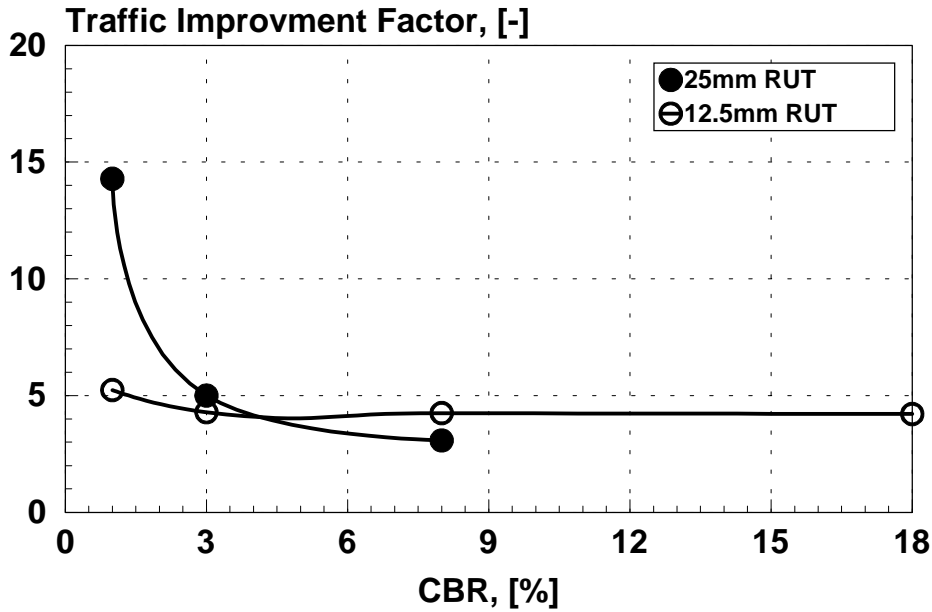


Figure 9. Traffic improvement factor vs. CBR for two rut depth.

AASHTO DESIGN METHOD FOR FLEXIBLE PAVEMENTS

The AASHTO method utilizes an index named “structural number” (SN) to indicate the necessary combined structural capacity of all pavement layers overlying the subgrade. SN is a function of subgrade strength, expected traffic intensities, pavement life, and climatic conditions.

For unreinforced pavement sections, a simple design equation is used in AASHTO method (based on AASHTO interim guide, 1981).

$$SN = a_1 \cdot d_1 + a_2 \cdot d_2 + a_3 \cdot d_3 \quad (1)$$

where the subscripts 1, 2 and 3 refer to the asphalt wearing course, aggregate base course and subbase course (if applicable), and a_1 , a_2 , a_3 are the layer coefficient used to characterise the structural capacity of different layers in the pavement system, d_1 , d_2 and d_3 are their thickness. The better the course material, the higher the layer coefficient. The structural number is directly proportional to the layer coefficients and their thickness.

Design details based on design charts are straight forward and outlined in the AASHTO interim guide. The input design parameters are the average subgrade CBR value, design terminal serviceability index P_t , the regional factor R, and the total equivalent 80 kN (18-kip) single axle loads (EAL) throughout the design life. Based on these design values, the required structural number can then be calculated. After the layer coefficients of asphalt wearing course, base course and subbase course are determined, the required thickness of the base course (or asphalt layer) can be calculated.

MODIFIED AASHTO METHOD WITH GEOGRID REINFORCEMENT

In the modified AASHTO method the structural contribution of geosynthetics on flexible pavements is quantified by the increase in the structural layer coefficient of the aggregate base course. Equation (1) now becomes

$$SN = a_1 * d_1 + a_2 * (\alpha_r / \alpha_u) * d_2 \quad (2)$$

where a_r/a_u is the layer coefficient ratio (greater than 1). a_r/a_u can be determined by results obtained from empirical tests on flexible pavement system with and without a geogrid reinforcement.

$$\alpha_r / \alpha_u = \frac{(SN_r - a_1 * d_1)d_u}{(SN_u - a_1 * d_1)d_r} \quad (3)$$

where SN_r and SN_u are the structural numbers for reinforced and unreinforced pavement systems respectively, d_r and d_u are the thickness of the aggregate base course. The asphalt thickness was kept constant for all reinforced and unreinforced sections. The influence of the asphalt layer to the layer coefficient ratio is neglected in the calculations. This assumption eliminates the need to assume a layer coefficient for the asphalt for the calculation of the layer coefficient ratio. Then equation (3) becomes

$$\alpha_r / \alpha_u = \frac{SN_r * d_u}{SN_u * d_r} \quad (4)$$

Figure 10 presents the layer coefficient ratio based on empirical pavement testing with and without a geogrid reinforcement (serviceability index $P_f = 2$, regional factor $R = 1$).

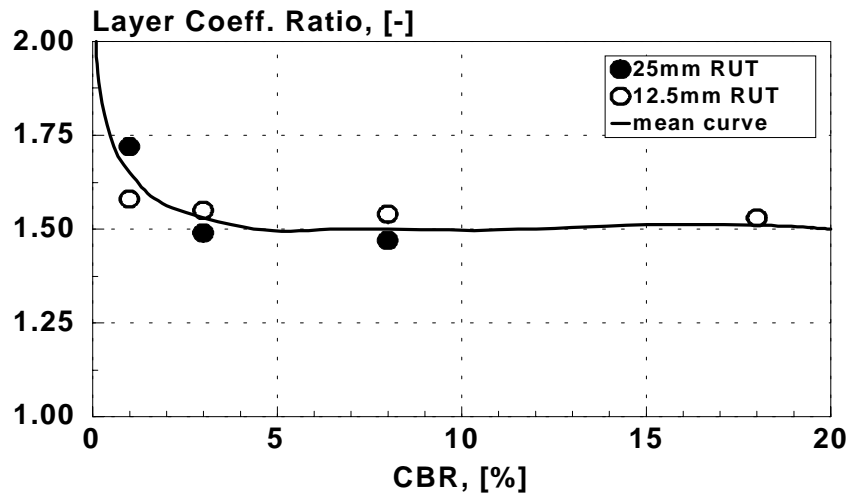


Figure 10. Layer coefficient ratio vs subgrade CBR

As a result, a reduction in aggregate thickness can be achieved by equation (2)

$$d_2 = \frac{SN - a_1 * d_1}{(\alpha_r / \alpha_u) * a_2} \quad (5)$$

or instead, the asphalt thickness can be reduced

$$d_1 = \frac{SN - (\alpha_r / \alpha_u) * a_2 * d_2}{a_1} \quad (6)$$

DESIGN EXAMPLE AND DESIGN CHARTS

Design Parameters:

Average subgrade CBR = 5%

total 80 kN (18 kip) equivalent single axle load application: 1,500,000

design terminal serviceability index $P_t = 2$

regional factor $R = 1.5$

layer coefficient for asphalt surface = 0.44

layer coefficient for the aggregate base course = 0.15

maximum permissible rut depth = 12.5 mm

The layer coefficient ratio is taken 1.5 (based on Figure 10)

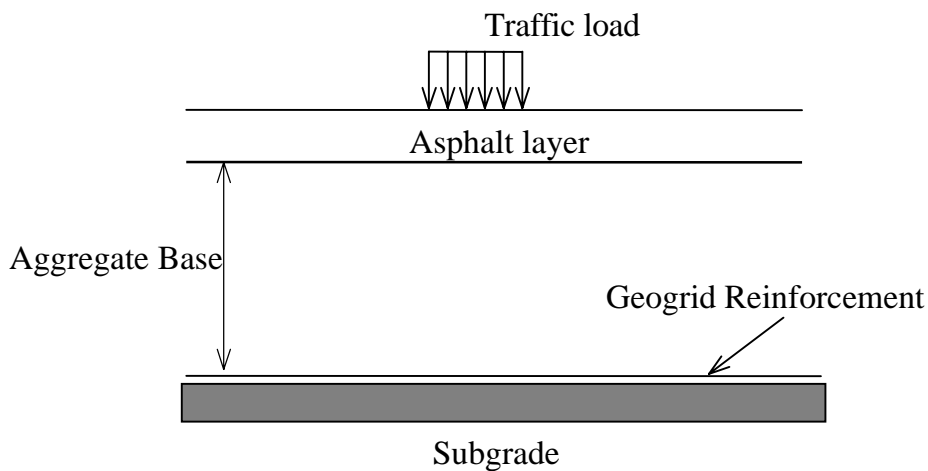


Figure 11. Geosynthetic reinforcement in base reinforcement application.

Calculation Results:

The aggregate thickness without geogrid is equal to 42.52 cm (16.74 in); the aggregate thickness with the geogrid = 28.35 cm (11.16 in). A saving of 14.17 cm (5.58 inches) of aggregate is achieved when using a geogrid reinforcement in this example.

Figure 12 is a design chart demonstrating the required fill thickness in pavement system with and without a geogrid reinforcement. The data used in this chart: asphalt thickness is 6.35 cm (2.5”), the regional factor is 1.5, the service index is 2.5, and three total equivalent standard axle loads. Figure 13 is the design chart for pavements with serviceability index equal to 2.

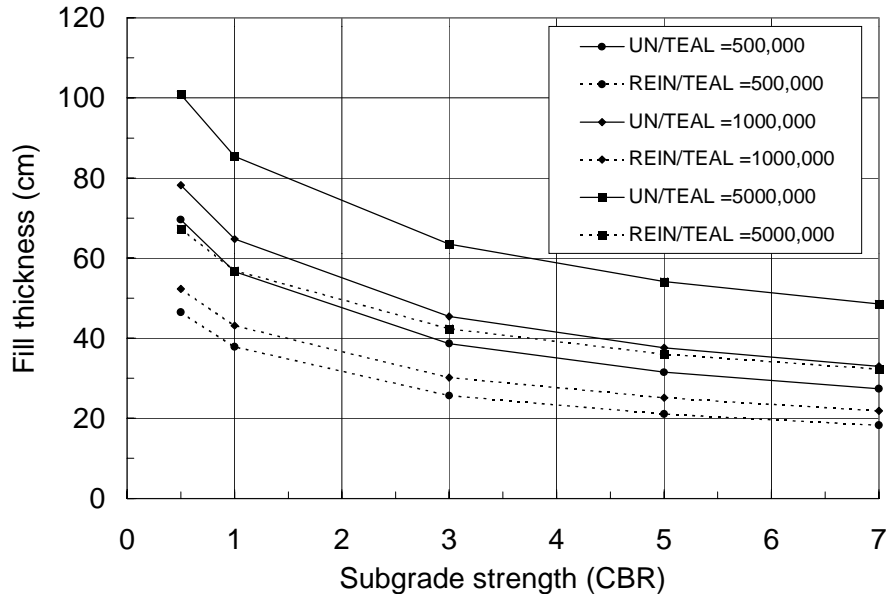


Figure 12. Aggregate fill thickness vs. subgrade strength ($P_t = 2.5$)

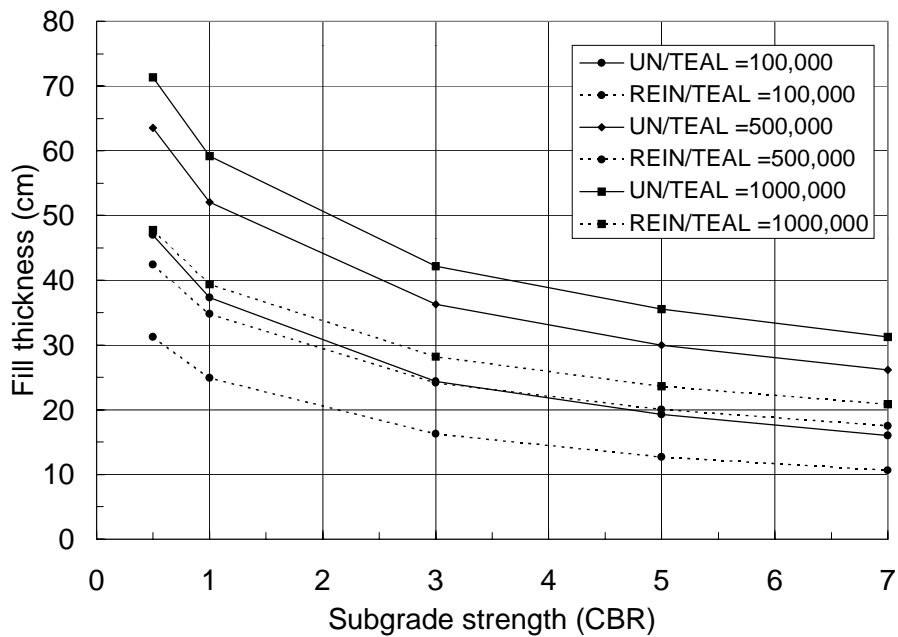


Figure 13. Aggregate fill thickness vs. subgrade strength ($P_t = 2.0$)

COST SAVING ANALYSIS

Cost savings when using a geogrid reinforcement in a pavement system will vary by project. Using the design calculation from the above example, it can be demonstrated as follows: Using an average cost of $\$32.7/\text{m}^3$ ($\$25/\text{yd}^3$) for graded aggregate base (GAB) in place, and a cost of $\$1.7/\text{m}^2$ ($\$1.4/\text{yd}^2$) for geogrid in place, the net savings for utilizing a geogrid reinforcement in this example is $\$2.93/\text{m}^2$. The cost saving per square meter for various traffic, subgrade strength, and serviceability index is presented in Figure 14, and 15.

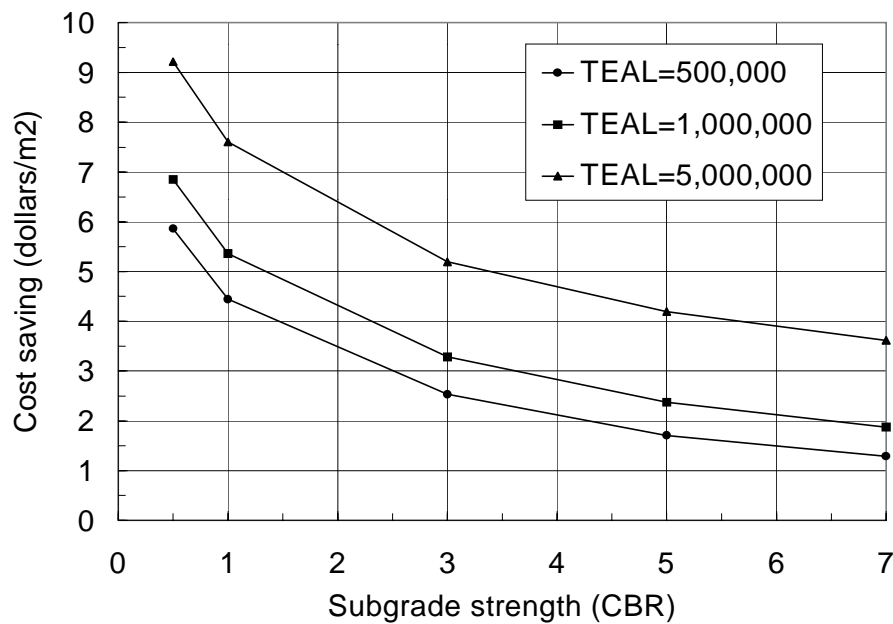


Figure 14. Cost savings in pavement with a geogrid reinforcement ($P_t = 2.5$)

CONCLUSIONS

The testing results obtained from this experimental research program demonstrated that a geogrid reinforcement placed at the subbase/aggregate interface effectively increases the service life of a paved road. Geogrid reinforcement provides a more uniform load distribution and a deduction in the maximum settlement both at the asphalt-aggregate and aggregate-subgrade interfaces.

A modified AASHTO design method capable of incorporating the effect of geogrid reinforcement is developed. The contribution of geogrid reinforcement to pavement system is quantified by the increase in the structural layer coefficient of the aggregate. The layer coefficient ratio was found to be between 2 to 1.5, depending mainly on the subgrade CBR. Design example is provided. Design charts are developed to facilitate preliminary design. Cost analysis is conducted comparing geogrid reinforced pavement to conventional unreinforced pavement. Figures 14 and 15 demonstrate that geogrid reinforcement is a cost effective solution to flexible pavement system.

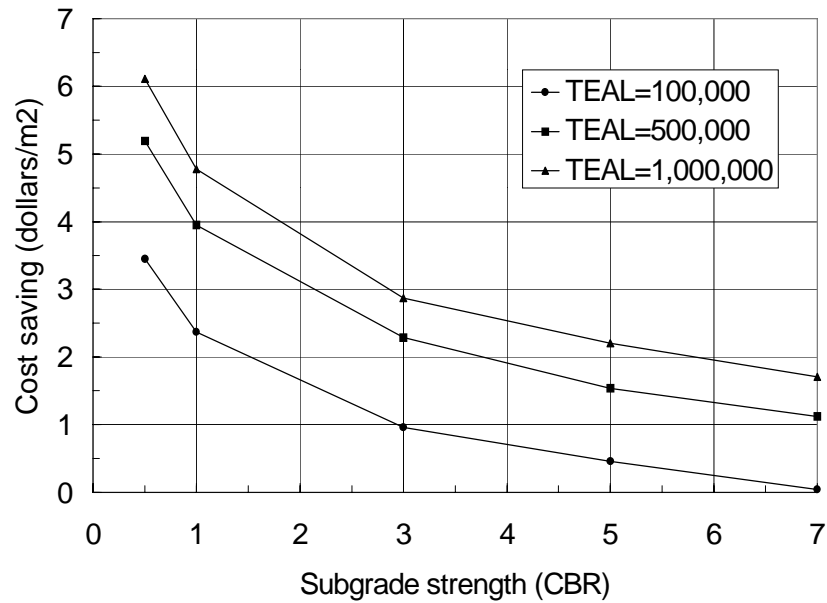


Figure 15. Cost savings in pavement with geogrid reinforcement ($P_t = 2.0$)

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