Technical Note by J.G. Collin, T.C. Kinney and X. Fu

FULL SCALE HIGHWAY LOAD TEST OF FLEXIBLE PAVEMENT SYSTEMS WITH GEOGRID REINFORCED BASE COURSES

ABSTRACT: The use of geosynthetics to improve the performance of flexible pavements has increased significantly over the last decade. This paper describes a full scale testing research program that used a 20 kN moving wheel load to determine the benefit of using a stiff biaxial geogrid between the base and subgrade of a flexible pavement system. The traffic benefit ratio (TBR) was defined as the ratio of the number of load cycles of a stiff geogrid reinforced section, to the number of load cycles of an unreinforced section for a given level of performance. The TBR values ranged from 2 to over 10 for the conditions tested. Traffic benefit ratio values between 2 and 4 appear to be reasonable for use in pavement design.

KEYWORDS: Base reinforcement, Geogrid, Wheel load, Deformation, Traffic benefit ratio.

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1 INTRODUCTION

The use of geosynthetics to enhance the performance of flexible pavements has experienced significant growth over the last decade. Geotextiles are being used more frequently as separators between the subgrade soil and the aggregate base of paved roads. Geogrids are being used to increase the performance of the aggregate base by acting as a composite material with improved performance characteristics.

The growth of the use of geosynthetics for these applications has been supported by considerable research on both subgrade improvement and base reinforcement of flexible pavements (Al-Qadi et al. 1994; Barksdale et al. 1989; Christopher and Holtz 1991; Giroud et al. 1984; Haas et al. 1988; Milligan et al. 1986; Webster 1992). In this paper, subgrade improvement is a term used to describe the improved subgrade stability of unpaved roads by the inclusion of a geosynthetic (geotextile or geogrid) at the base-subgrade interface. Base reinforcement is a term used to describe the improved performance of the aggregate base of a flexible pavement system when reinforced with a geosynthetic (geogrid or geotextile), and is the focus of this paper.

The design of flexible pavements is based on theory developed with the aid of laboratory and field testing, and experience. The beneficial effects of using geosynthetic reinforcement in road sections has been studied both theoretically and experimentally. Laboratory model testing has been performed where the load has been applied cyclically through a stationary loading plate (Al-Quadi et al. 1994; Haas et al. 1988; Valsangkar and Holm 1993). Few studies have used moving wheel loads (Barksdale et al. 1989; Chan et al. 1989). The study presented herein is one of the first to use highway loading on full scale road sections. Design methodologies for the use of geosynthetics in road sections are largely empirical, and are expressed in terms of the benefit of having reinforced the road section (traffic benefit ratio, TBR). The geosynthetic reinforcement is typically not theoretically incorporated into the design process as one of the design elements.

The University of Alaska, in conjunction with Tensar Earth Technologies, constructed a large scale test facility to test reinforced pavement sections with moving wheel loads that simulated highway traffic. The research at the University of Alaska was specifically focused on testing pavement sections using moving wheel loads to acquire empirical data to better model highway loading.

2 GEOGRID RESEARCH

The concept of adding tensile reinforcement to the base course of a flexible pavement system by the inclusion of a geosynthetic has been evaluated by many researchers over the last decade. This research has taken the form of small scale laboratory plate load tests (Al-Quadi et al. 1994; Haas et al. 1988; Valsangkar and Holm 1993), theoretical evaluations using finite element analysis (Barksdale et al. 1989; Bauer and Mowafy 1988; Burd and Houlsby 1986), and full scale, 40 kN and 130 kN wheel loads (Fannin and Sigurdsson 1996; Webster 1992).

In Sections 2.1 to 2.3, a brief review of two references that set the background for this research program on geogrid reinforced aggregate base courses is presented.

2.1 University of Waterloo (Haas et al. 1988)

A comprehensive program investigating geogrid reinforcement of granular base courses of flexible pavements was carried out at the University of Waterloo in 1984.

The program consisted of repeated load tests on varying thicknesses of reinforced and non-reinforced granular bases.

The purpose of the research was to determine the benefit, or TBR, of incorporating a stiff biaxial geogrid (Geogrid A in Table 1) in the granular base of a three layer pavement system comprising an asphalt concrete surface, a granular base and subgrade. Traffic benefit ratio is defined as the number of load cycles to a given deformation in a reinforced section, to the number of load cycles required to get the same deformation in the control, non-reinforced section.

Variables in the testing program included: subgrade strength (California bearing ratio (CBR) values of 1, 3.5 and 8); aggregate base thickness (150, 200 and 300 mm); asphalt concrete thickness (75 and 100 mm); and reinforcement location (bottom, middle and top of the aggregate base course).

It was found that for subgrade CBR values ranging from 1 to 8, the incorporation of the stiff biaxial geogrid at the bottom of the base course provided a TBR value of approximately 3. For thick aggregate base courses the geogrid provided better performance when it was located at mid-height of the base course rather than at the bottom of the base course. Reinforcement placed at the top of the aggregate base course provided no improvement.

2.2 U.S. Army Corps of Engineers - Vicksburg, Mississippi, USA (Webster 1992)

In 1990 and 1991 the US Army Corps of Engineers investigated geogrid reinforced base courses in flexible pavements for light aircraft. This investigation involved full scale field testing of geogrid reinforced pavement sections using a 130 kN single tire load.

Table 1. Geogrid properties.

Geogrid	Structure	Polymer composition	Mass/unit area (g/m^2)	Aperture size (MD × XD) (mm)	5% secant modulus MD/XD (kN/m)	Secant aperture stability modulus (cm-kg/degree)
A	Punched/ Drawn	PP	215	25 × 33	211/277	4.4
B	Punched/ Drawn	PP	306	25 × 33	320/305	8.5
C	Bi-oriented	PP	198	43 × 46	261/351	3.0
D	Woven	PET/PVC coating	305	20 × 20	207/133	2.0
E	Woven	PET/PVC coating	192	20 × 18	223/178	3.1
F	Woven	PET/Latex coating	187	30 × 33	247/117	2.1

Notes: Secant aperture stability modulus is the resistance to in-plane rotation measured in units of cm-kg/degree and is calculated as the ratio of a standard 20 cm-kg moment to the resultant in-plane rotation (Yuan 1993). The torsion is applied to the central junction of a 225 mm × 225 mm specimen in plan area restrained at its perimeter. Mass/unit area measured using ASTM D 3776. 5% secant modulus measured using ASTM D 4595. MD = machine direction; XD = cross machine direction; PP = polypropylene; PET = polyester; PVC = polyvinyl chloride.

Based on a literature review of full scale field tests, the US Army Corps of Engineers concluded that for subgrade CBR strengths of 1.5 to 5.0, flexible pavements with geogrid reinforced base courses could carry approximately 3.5 times more traffic repetitions than equivalent non-reinforced sections based on a rut depth criterion of 38 mm. The objective of this research was to use full scale traffic tests to determine the TBR value of flexible pavements travelled by light aircraft.

The US Army Corps of Engineers research program evaluated six different geogrids. Two punched/drawn polypropylene geogrids (Geogrid A and B, Table 1), one bi-oriented polypropylene geogrid, and three woven polyester geogrids.

Surface deformation measurements were taken after a certain number of load cycles on each test section. The results for the pavement section comprising 50 mm of asphalt concrete, 355 mm of aggregate base and a subgrade CBR value of 3 are presented in Figure 1. The TRB values at 25 mm deformation for Geogrid A and B were 2.7 and 4.7, respectively. The TRB values for the other geogrids varied from 0.9 to 1.6. The performance of the various geogrids could not be directly related to any current index test. In fact, Geogrid A and C had very similar index test properties but very different TBR values. The secant aperture stability modulus, determined from the torsional rigidity test developed by Kinney and Xiaolin (1995) as part of the US Army Corps of Engineers research, appears to be a good indicator of the relative performance between different geogrids for this application.

2.3 Discussion of Previous Research

The research performed by Haas et al. (1988), using small scale laboratory plate load tests, clearly demonstrated an improvement in performance (cycles of load to a predetermined deformation) when the pavement section was reinforced with a stiff biaxial

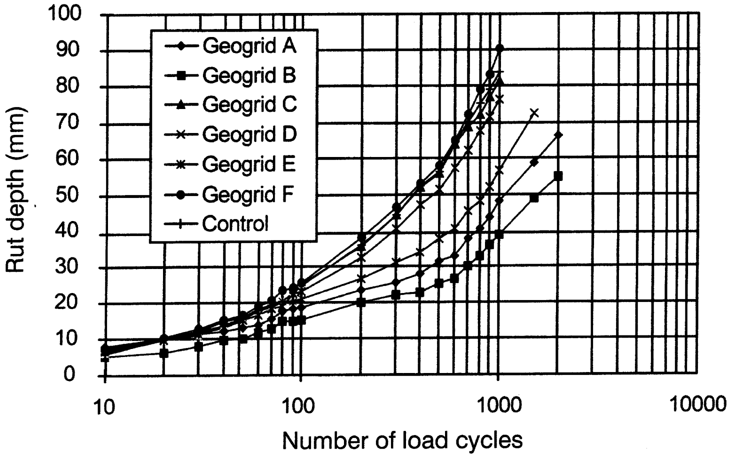

Figure 1. Rut depth versus number of load cycles for a pavement section comprising 50 mm of asphalt concrete, 355 mm of aggregate base and a subgrade CBR value of 3 (Webster 1992).

geogrid (Geogrid A). The US Army Corps of Engineers research also clearly demonstrated that under very large moving wheel loads (130 kN), a marked improvement in pavement performance was observed when the pavement was reinforced with the stiff biaxial geogrids (Geogrid A and B). With the results of this research, it was believed that stiff biaxial geogrids would provide improved performance of flexible pavements subjected to highway loading. The subsequent research at the University of Alaska was conducted to substantiate that when stiff biaxial punched and drawn geogrids are incorporated into the pavement system and subjected to highway traffic loads, the performance of the flexible pavement system is enhanced.

3 TESTING PROGRAM

3.1 Test Section Construction

A full scale laboratory highway loading test program was conducted at the University of Alaska. The test facility consists of a 1.2 m deep × 2.4 m wide × 14.6 m long box in which model road sections are constructed.

The full scale test program included four test sections within the box. Two of the four sections had stiff biaxial geogrids placed at the interface between the subgrade soil and the base course. The third section had two layers of stiff biaxial geogrid, one placed at the base-subgrade interface and one placed within the aggregate base. The final section had no geogrid and served as the control section. The thickness of subgrade was tapered along the length of each test section so that the performance of a range of base thicknesses could be evaluated. Table 2 provides a description of each test section, and Figure 2 shows a plan view and profile of the test setup.

The pavement section for all test sections consisted of 50 mm of hot mix asphalt concrete, over a compacted crushed rock base (varying in thickness from 150 to 460 mm) and a soft clay subgrade. The subgrade soil was a clayey silt (approximately 22% clay size particles), locally named Healy Clay. The subgrade was placed at a dry unit weight of approximately 16 kN/m^3 and at a water content of 21%. Field CBR tests were performed in the center of each test section before placing the base coarse. The CBR values ranged from a high of 2.7 to a low of 1.6 with an average value of 1.9. The particle size distribution of the base material is shown in Figure 3. The maximum dry unit weight was 22 kN/m^3, at a water content of 7%. The in-place unit weight of the base material was approximately 20 kN/m^3 with an in-place average CBR value of 15.

Table 2. University of Alaska test program.

Section	Base thickness (mm)	Geogrid type and location
1	150 - 300	Geogrid B at base-subgrade interface
2	300 - 150	Geogrid A at base-subgrade interface
3	150 - 460	No geogrid - control section
4	460 - 200	Geogrid A at base-subgrade interface, and Geogrid A at mid-height in the base course

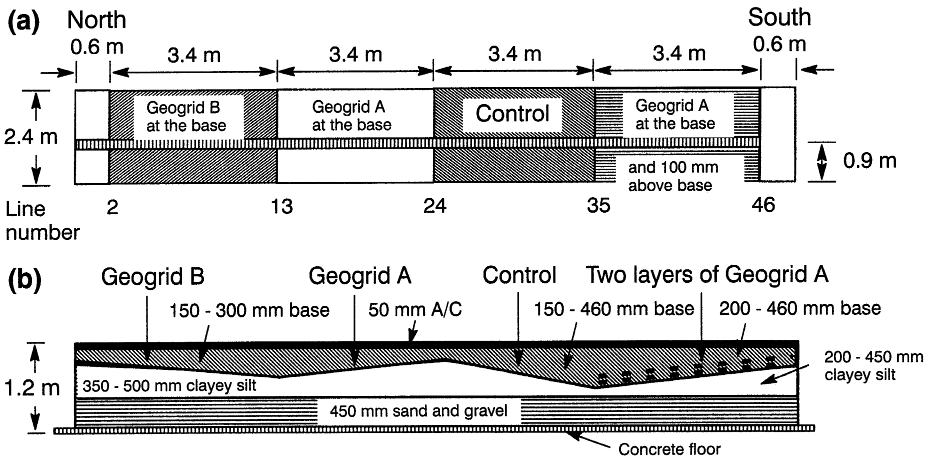

Figure 2. University of Alaska test setup: (a) plan view; (b) cross section.

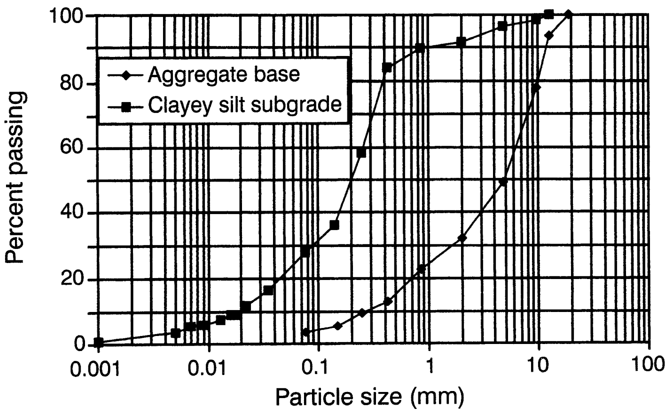

Figure 3. Particle size distribution for aggregate base and subgrade Healy clay.

The asphalt concrete used for all pavement sections was a standard hot mix used by the State of Alaska, Department of Transportation, on primary roads. The maximum dry unit weight of the asphalt was 23 kN/m^3. In-place unit weight ranged between 21.5 and 22.3 kN/m^3, with an average value of 22 kN/m^3. Two stiff biaxial geogrids (Geogrid A and B) were used in the pavement sections. The material properties for these geogrids are provided in Table 1.

3.2 Wheel Load

The load was applied to the pavement section through a single tire inflated to an internal pressure of 550 kPa. The tread was 230 mm wide and the tire diameter was 1.05 m. A 20 kN load was applied to the tire when traveling from the south end of the box to the north end. A 9 kN load was applied in the reverse direction (dead weight of the load cart). The wheel moved at a speed of 1.2 m/s. The wheel load was applied slightly off the center line of the test box to allow additional testing (plate load tests) on the other side of the center line. The center line of the wheel track was 900 mm from the edge of the box. Results of the plate load tests are not reported in this paper.

As previously mentioned, the purpose of this testing program was to compare the performance (load cycles to failure) of the reinforced and non-reinforced pavement sections. Since the traffic on one side of a road travels in one direction only, an attempt was made to reproduce realistic highway loading by applying the full load on the wheel in one direction, and the minimum load possible with the equipment, in the reverse direction. The recorded traffic count includes only the passes in the heavily loaded (20 kN) direction. The total equivalent traffic passes is likely between the number of heavily loaded passes and twice that number.

3.3 Data Acquisition

The TBR value is defined in terms of surface rutting. The data acquisition program was, therefore, based on measuring surface rutting. The method used to measure surface rutting (displacement) was to place an aluminum bar across the pavement surface at predetermined locations and measure down from the bar with a micrometer caliper to the pavement surface.

The test box was marked every 0.3 m along the length of the box, starting at the north end with Station 0 and ending at the south end with Station 48. Measurements of surface deformation were taken at every even numbered station along the length of the track. Figure 2 shows the line number corresponding to the data acquisition program.

At the points where the slope changes (lines 2, 13, 24, 35 and 46), the wheel load was distributed across two different pavement sections. The results in the vicinity of these lines were obscured by the transition from one section to another and were not used in the analysis of results.

3.4 Test Results

For presentation and comparison purposes, the performance of Geogrid A, Geogrid B and the non-reinforced pavement sections with base thicknesses of 180, 235 and 290 mm are discussed. The results for the pavement section reinforced with two layers of geogrid is beyond the scope of this paper.

Figures 4 to 6 illustrate the difference in performance of the control section and the two reinforced sections with base thicknesses of 180, 235, and 290 mm, respectively. Figure 4, the 180 mm thick base case, shows a maximum deformation, or rut depth, for the control section of approximately 47 mm after 1014 load cycles (data for the control section for additional load cycles was not available as the section was unpassable with the load cart). After 1014 load cycles, the performance of both reinforced sections is very similar, both in the shape and depth of the rut. The maximum deformation of the reinforced sections at 1014 load cycles was less than 34 mm.

Figure 5, the 235 mm thick base case, shows a considerable decrease in the rut depth when compared to the 180 mm thick base for controlled and reinforced conditions - less than 30 mm. Figure 6, the 290 mm thick base case, shows a more dramatic increase in

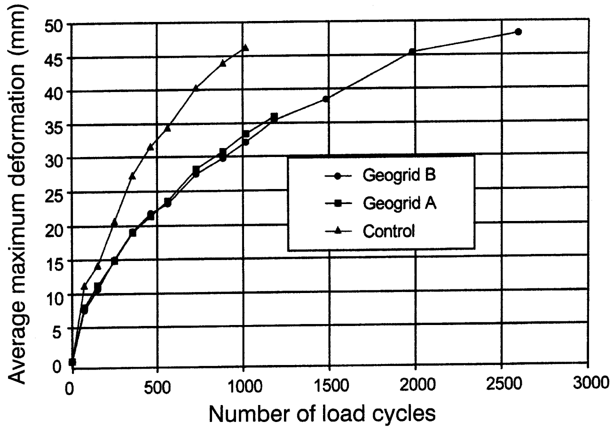

Figure 4. Deformation versus number of load cycles for 180 mm of aggregate base.

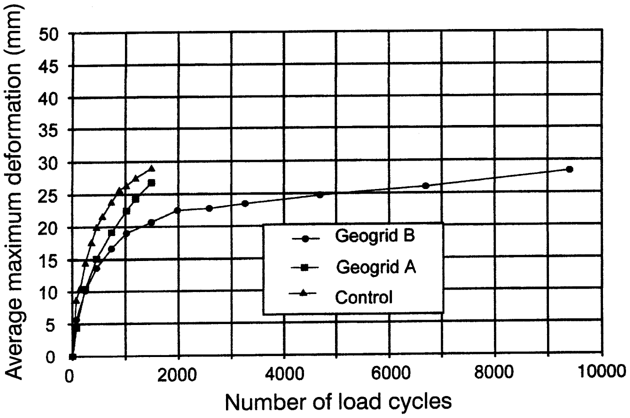

Figure 5. Deformation versus number of load cycles for 235 mm of aggregate base.

the number load cycles (38,348) for a smaller rut depth than the 180 mm thick base case. The shape of the ruts for the three different base thicknesses indicate less upward heave outside the wheel load for thicker base courses.

The curves in Figure 6 indicate high deformation rates for all sections up to 1000 to 2000 load cycles. At this point a distinct "knee" in the curve developed; after this "knee", the stiffness of the pavement section is significantly higher, and the curve becomes linear. This phenomena was also observed in Figure 5 for Geogrid B. When comparing the control section in Figures 5 and 6, it is shown that the magnitude of the deflection at the knee decreases with increasing base course thickness. Figure 6 also demonstrates that the magnitude of the deflection at the knee in the curve was reduced by 20 to 30% by the inclusion of Geogrid A or B.

The maximum TBR value provided by the geogrid reinforced sections occurs at the deflection, or knee, of the control section curve. This is shown in Tables 3 and 4, where

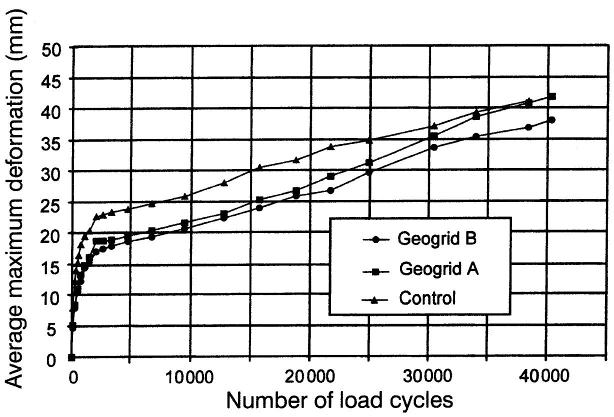

Figure 6. Deformation versus number of load cycles for 290 mm of aggregate base.

the maximum TBR value for Geogrid A occurs at a deformation of 19 mm for a base thickness of 275 mm, 25 mm at 250 mm, and 32 mm at 225 mm. For a specific base thickness, the TBR value decreases as deflection increases beyond the control section knee. This decrease occurs because the TBR value is a ratio of the reinforced performance to the control performance and not because of a decreasing number of additional load cycles carried by the reinforced section.

Table 3. Traffic benefit ratio values for Geogrid A.

Base thickness (mm)	TBR values for Geogrid A					
	Deformation (mm)					
	12	19	25	32	38	Average
175	1.6	1.8	1.7	2.1	-	1.8
200	1.6	1.5	1.8	2.4	-	1.8
225	1.6	1.5	1.7	3.0	2.9	2.2
250	1.6	2.4	3.3	2.4	1.6	2.3
275	1.9	3.2	2.6	1.7	-	2.4
Average TBR value	1.7	2.1	2.2	2.3	2.3	2.1

Table 4. Traffic benefit ratio for values Geogrid B.

Base thickness (mm)	TBR values for Geogrid B					
	Deformation (mm)					
	12	19	25	32	38	Average
175	1.8	1.8	2.1	2.2	2.3	2.0
200	1.9	2.0	2.8	5.0	6.4	3.6
225	2.1	2.4	6.1	5.8	5.4	4.4
250	2.3	3.8	10.0	4.3	2.8	4.6
275	2.4	5.1	3.2	1.9	1.5	2.8
Average TBR value	2.1	3.0	4.8	3.8	3.7	3.5

Figures 7 to 9 show plots of the average maximum deformation versus number of load cycles for the control and reinforced sections with the same base thicknesses (180, 235, and 290 mm). For each base thickness (e.g. 235 mm), and for the same deformation (e.g. 25 mm), the section reinforced with Geogrid B can carry more load cycles than the section reinforced with Geogrid A, and the section reinforced with Geogrid A can carry more load cycles than the control section.

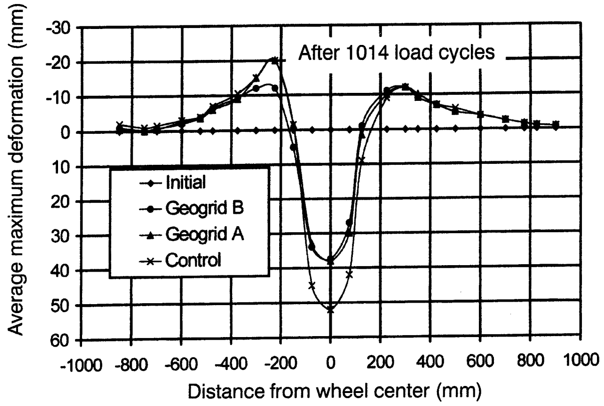

Figure 7. **Cross section of 180 mm aggregate base after 1014 load cycles.**

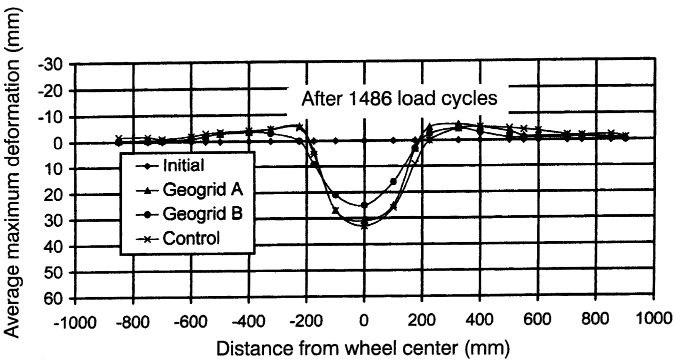

Figure 8. **Cross section of 235 mm aggregate base after 1486 load cycles.**

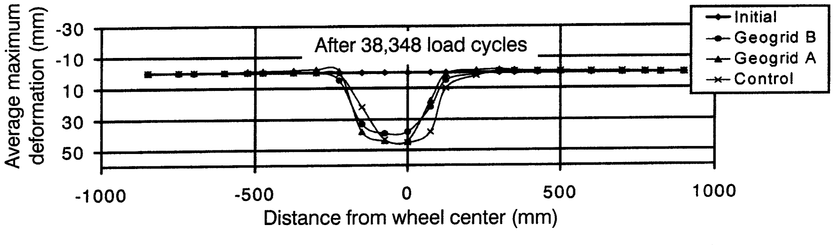

Figure 9. **Cross section of 290 mm aggregate base after 38,348 load cycles.**

Figures 7 to 9 appear to suggest that the TBR is a function of the aggregate base thickness as well as the type of reinforcement. While not reported here, it was observed that for very thin base sections (150 mm) failure occurs rapidly, and the inclusion of reinforcement had only a marginal benefit. With a 150 mm base thickness the pavement section was obviously under designed and although the reinforcement increased the number of load cycles to a specified deformation criterion (TBR values of approximately 1.6), the pavement still failed rapidly. These light pavement sections, with subgrades possessing such low CBR values, are not realistic designs but were included in the test program to determine the range of base thickness where improved performance can be expected with the inclusion of a geogrid. With very thick aggregate base sections (e.g. 350 mm), the benefit of the reinforcement is diminished, as less load reaches the reinforcement.

Figure 10 shows the TBR values for Geogrid A and B as a function of base thickness for a deformation of 25 mm. The TBR values for Geogrid B appear to be quite sensitive to base thickness; with a base thickness of 175 mm the TBR was 2.1, and with a base thickness of 250 mm the TBR was 10.0. As can be seen in Figure 10, the benefits of Geogrid A are less sensitive to base thickness. For a deformation of 25 mm, the average TBR values for Geogrid A and B are 2.2 and 4.8, respectively.

4 CONCLUSIONS

This study confirms that stiff biaxial geogrid reinforcement placed between a poor clay subgrade and a base course aggregate of a flexible pavement subjected to highway traffic loads can substantially increase pavement performance. In the geogrid reinforced test sections, the number of wheel loads before failure increased from 50 to 900% over a range of pavement thicknesses of 180 to 290 mm, and pavement surface deformations of 50 to 150 mm. The geogrid reinforcement decreased the initial pavement deformations that occur during the first several hundred load cycles before the section stiffens. The geogrid reinforcement also caused the deflection versus load cycle curves to flatten and become almost linear.

The traffic benefit ratio (TBR) provided by the reinforcement increased with increasing base course thickness and with increasing pavement deflection to a maximum of 3.3 for Geogrid A and 10 for the heavier Geogrid B. Beyond these maximums the TBR value decreased, but the additional number of load cycles provided by the geogrids increased or remained constant. The TBR maximum values were developed at surface

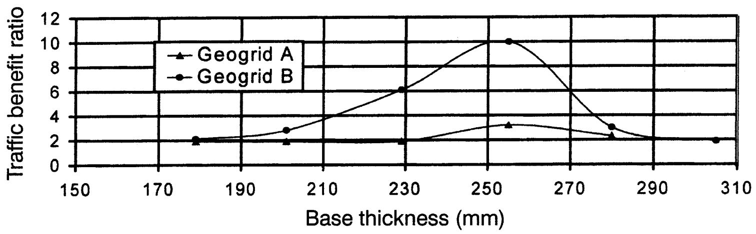

Figure 10. TBR values for varying aggregate base thicknesses at a deformation of 25 mm.

deflections of 25 mm or less for base thicknesses greater than 250 mm. For thinner base thicknesses, the maximum values were reached after greater deflections. At a deflection of 25 mm, the average TBR values for Geogrid A and B were 2.2 and 4.8, respectively.

Previous research by Haas et al. (1988) and Webster (1992) established a TBR value of 3.0 to 2.7, respectively, for Geogrid A. Webster obtained a TBR value of 4.7 for Geogrid B. These results are in reasonable agreement with those obtained in the University of Alaska test program despite the significant differences in the three programs. For flexible pavements constructed on subgrades with a CBR of 3 and with base course thicknesses between 175 and 300 mm, it can be conservatively estimated that the geogrids tested will increase the pavement life by approximately 2 to 4 times with respect to unreinforced pavements.

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