Geogrid Reinforcement of Granular Bases in Flexible Pavements

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A comprehensive laboratory research program to investigate geogrid reinforcement of granular base layers of flexible pavements was carried out at the University of Waterloo and involved repeated load tests on varying thicknesses of reinforced and unreinforced granular bases. Other controlled variables included reinforcement location and subgrade strength. The purpose of this paper is to explain geogrid reinforcement mechanisms in granular base applications through analysis of stress, strain, and deflection measurements. The results of that research are first compared with fabric reinforcement and failure criteria. For high-deformation systems both fabric and grid can be effective in tension membrane action, but for low-deformation systems the interlock and confining action of a grid is required to provide effective reinforcement. The Waterloo work showed that permanent deformation of both types of systems can be significantly reduced by using geogrid reinforcement in the granular base. The reinforcement mechanisms involved with geogrid reinforcement of granular bases, and how the stress-strain-deflection response of the structure varies, are discussed. It is concluded that, for optimum effect, geogrid reinforcement should be placed at the base-subgrade interface of thin base sections and near the midpoint of thicker bases. Moreover, the zone of such placement should not involve elastic tensile strains in the grid that are greater than 0.2 percent. Under these conditions, geogrid reinforcement can be highly effective in reinforcing the granular base material and thereby extend the life of a structure.

The function of reinforcement is to strengthen by additional assistance, material, or support. For the same reason that steel reinforcement is embedded in concrete, reinforcing materials can be incorporated into the base layer of flexible pavements so that the two materials act together to resist forces. Interlock or positive bond between the reinforcement and the aggregate particles is required to truly reinforce the granular base of flexible pavements. Because an unbound base cannot take tension, the function of the interlock or bond is to mobilize the strength of the reinforcement and impart this resisting force to the base. In addition to possessing the appropriate physical properties to interlock with the base layer, a pavement reinforcing material should possess the following mechanical properties:

1. High tensile modulus to resist stretching under load;
2. Dimensional stability to resist radial stresses without deforming, warping, or stretching;
3. Elastic response under dynamic loading;
4. Resistance to plastic strain with repeated load applications; and
5. Inertness and durability.

For more than a decade geotextile fabrics have been used for subgrade stabilization of soft foundation soils. In subgrade stabilization, the separation function of the fabric is the key to performance. It prevents granular base material from punching into soft foundation soils under the wheel or track loads of construction vehicles. Because base punching or localized shear failure is prevented, the subgrade can develop its full bearing capacity. This separation function provides an increase in subgrade load capacity when the soil shear strength is quite low (< 1,000 psf) and the subgrade is prone to deep rutting. As subgrade shear strength increases (> 1,000 psf), however, these benefits diminish.

Fabric applications have been limited for the most part to high-deformation systems in which surface deflections of 3 in. or greater are allowable—for example, haul and access roads over soft ground. But there is little if any evidence to support improvements via fabric separation or reinforcement in low-deformation systems.

Recent developments in geogrid technology, however, suggest that the interlock and tensile modulus characteristics of certain grid products might be beneficial as reinforcement within the granular base of low-deformation systems, such as flexible pavements, as well as high-deformation systems. This was clearly demonstrated in the University of Waterloo research program (*1–3*), which is subsequently discussed.

In addition to possessing the previously mentioned properties, grids can be manufactured with opening sizes compatible with typical base course maximum particle sizes (i.e., 1 to 1½ in.). The grids provide a most efficient means for carrying tensile stresses transmitted through the base course. The result is confinement of the aggregate particles and a reduction in strain due to wheel loads.

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The purpose of this paper is to provide some general background, summarize the results of the research program carried out at the University of Waterloo, examine the mechanisms that govern the performance of grid reinforcement, and define the optimum conditions for effective reinforcement of the base layer of flexible pavements.

BACKGROUND

In recent years, several laboratory and full-scale trials have been carried out to study the reinforcement potential of geotextiles and geogrids in both unpaved (high-deformation) and paved (low-deformation) roads. Through these programs, several reliable design methods have been developed. In addition, hundreds of installations have been observed by practicing civil and geotechnical engineers. Despite the vast amount of information available and increased experience with geotextiles and geogrids, many failures still occur because of a lack of understanding of how these materials affect the properties of the basic engineering materials (e.g., subgrades, engineering fills, and pavement materials) or how reinforcement affects the load response of the structure.

Even a review of the literature can be confusing because various studies indicate everything from inferior to superior performance of reinforced paved and unpaved roads compared with unreinforced structures. Several studies report conflicting observations about the optimum location for reinforcement, which ranges from the base-subgrade interface to a location near the top of the base. For example, studies by Halliday and Potter (*4*) and Ruddock et al. (*5*) concluded that the presence of a woven polyester geotextile had no effect on the structural performance of asphalt pavements. In both test programs the geotextile was placed at the bottom of the base course. A field test program by Barker (*6*) showed that grid reinforcement at the midpoint of a 6-in. base course of a flexible pavement had only a minor effect on reducing rutting beneath heavy aircraft loads. On the other hand, large-scale laboratory tests by Bathurst et al. (*7*) indicated that geogrid reinforcement placed in the upper section of railway ballast had a significant impact on reducing tie-ballast settlements over flexible subgrades. Similarly, plate loading tests on Reinforced Earth slabs at the Cooper Union School of Engineering showed decreasing settlement and higher bearing capacities with reinforcement layers placed close to the footing (*8*). In contrast, the Waterloo study showed that maximum rutting reduction benefits of grid reinforcement were evident when grid was placed within the lower half of the base course of flexible pavements.

To explain these apparent discrepancies, it is necessary to look more closely at the variables tested in each of the test programs and to examine the effects reinforcement has on the load response of a system. Variables that might result in apparent discrepancies in test results include type of structure; subgrade type and strength; failure criteria; static versus dynamic load; shape, size, and magnitude of load; and type and location of reinforcement.

Perhaps the most significant of these variables are the failure criteria used for drawing conclusions from a particular study. For example, a test program that considers failure at deformations of 2 in. or more would not be applicable to flexible pavement structures. Furthermore, cyclic load tests that cause initial deflections of more than 0.1 in. would also not be applicable to flexible pavements. In essence the structure being tested would be underdesigned as a flexible pavement but might be appropriate for a temporary haul road. The importance of the failure criteria is that they can dictate design parameters such as type and location of reinforcement and number of reinforcement layers.

For example, it has been shown by several investigators that deformations can be significantly reduced by the inclusion of reinforcement near the surface of an unbound base course. This is true for high-deformation systems because the initial deformations tension the reinforcement and allow it to carry tensile load through tension membrane action. Before it is tensioned, however, the reinforcement is actually in a zone of compression, and the initial deformation that is required to mobilize the reinforcement is typically greater than tolerable rut depths for flexible pavements.

Thus, for reinforcement to be effective in flexible pavement structures, it is apparent that the optimum location must be in a zone of tensile stress during the first load application and remain in a tensile zone throughout the design life. This location will be dictated by the shape, size, and magnitude of the design wheel loads as well as the strength characteristics of the pavement layers, including the subgrade.

WATERLOO TEST PROGRAM

The experimental program involved full-scale cyclic load tests on both reinforced and nonreinforced model pavement sections. These sections consisted of asphalt concrete 3 to 4 in. thick and aggregate base constructed over a sand subgrade. Variables in the test program included subgrade bearing capacity, base layer thickness, asphalt concrete layer thickness, and grid location within the base layer. The principal objectives of the experimental investigation were to

1. Develop equivalency factors for geogrid-reinforced granular base sections;
2. Develop structural design procedures for geogrid-reinforced flexible pavements using the equivalency factors developed in Objective 1; and
3. Analyze geogrid reinforcement mechanisms in flexible pavements through the use of stress, strain, and deflection measurements.

The experimental program was divided into six test series or "loops," each of which contained four separate tests. Each loop was carefully designed to control the key variables in order to isolate and examine the effects of geogrid

reinforcement. A summary of the test arrangements is given in Table 1.

Test Facility

The test facility at the University of Waterloo consisted of a large rectangular box, 15 ft × 6 ft × 3 ft, constructed of plywood reinforced by a steel frame and lined with galvanized steel sheeting.

Loads were applied by a steel plate 12 in. in diameter driven by a servohydraulic actuator rated at 13 kips. Each test section was subjected to an identical loading sequence that consisted of a series of dynamic loads followed by a single static load at predetermined cycle counts. The load applied to the pavement surface for both types of loading was 9,000 lb, which applied a pressure of 80 psi through the load plate. The configuration and magnitude of the applied load were selected to simulate a set of dual wheels under an equivalent 18-kip single axle load. Dynamic loads were applied at a frequency of 8 cycles per second.

Instrumentation

Each test set up was instrumented as shown in Figure 1. Five dial gauges were placed on the asphalt surface and load plate along with an actuator linear velocity displacement transformer (LVDT) to measure surface deflections and permanent deformations of the asphalt surface. In addition, foil-type strain gauges were placed on the mesh at several locations at increasing radial distances from the load center.

In selected tests, pressure cells were placed 1.5 in. below the top of the subgrade to compare differences in stress distribution in reinforced and unreinforced sections.

Subgrade

The prepared subgrade consisted of a very fine-grained beach sand (SP) (99 percent passing the No. 40 sieve, 32 percent passing the No. 100 sieve, 4 percent passing the No. 200 sieve). Because it had an almost uniform grain

TABLE 1 TESTS LOOPS, CONTROLLED VARIABLES, AND OBJECTIVES

Test No.	Asphalt Thickness (in.)	Base Thickness (in.)	Reinforcement Location Within Granular Base	Subgrade CBR	Objectives
Loop No. 1					
1	4	8	None	8	Location effect
2	4	8	Bottom	8	
3	4	8	Mid	8	
4	4	8	Top	8	
Loop No. 2					
1	3	8	None	3.5	Granular base thickness effect and softer subgrade effect
2	3	8	Bottom	3.5	
3	3	6	Bottom	3.5	
4	3	4	Bottom	3.5	
Loop No. 3					
1	3	10	Bottom	–[a]	Thicker granular effect; very weak, saturated subgrade effect; and grid location effect
2	3	8	Mid	–[a]	
3	3	10	None	–[a]	
4	3	12	None	–[a]	
Loop No. 4					
1	3	6	Bottom	1	Very weak subgrade and thickness effect
2	3	8	Bottom	1	
3	3	8	None	1	
4	3	12	Mid	1	
Loop No. 5					
1	2	6	Mid	1	Very weak subgrade and effect of pretensioning geogrid
2	3	6	Mid, tensioned	1	
3	3	12	Mid, tensioned	1	
4	3	12	None		
Loop No. 6					
1	3	12	Subgrade	<1	Very weak subgrade effect, reinforced subgrade effect, and 2 layers of reinforcement effect
2	3	12	Bottom	<1	
3	3	12	None	<1	
4	3	12	Mid and Base	<1	

[a]The subgrade started out at a CBR of 4 but due to loss of moisture became very strong toward the end of this loop.

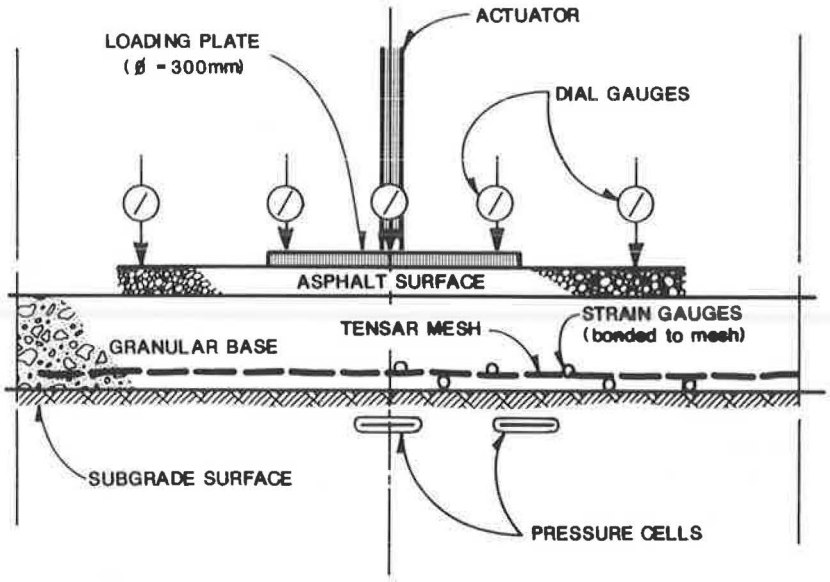

FIGURE 1 General arrangement of instrumentation.

size, it was ideal for varying support strength by changing the moisture content.

Aggregate Base

The base material for all tests was a well-graded crushed stone aggregate (GW) (100 percent passing the 1-in. sieve, 49 percent passing the No. 4 sieve, 4 percent passing the No. 100 sieve, 2.3 percent passing the No. 200 sieve). The optimum moisture content and maximum dry density were determined to be 6 percent and 146 lb/ft^2, respectively.

Asphalt Concrete

The asphalt surface layer for all tests was a dense-graded material with a maximum aggregate particle size of 0.6 in. and an 85/100 penetration grade asphalt cement.

Geogrid Reinforcement

The geogrid used for all tests was Tensar SS1 Geogrid. The key performance properties of this grid are given in Table 2.

TEST RESULTS

In addition to the first two objectives of evaluating the potential of geogrids for effective reinforcement of flexible pavements and developing design relationships, the third objective of the test program was to analyze the reinforcement mechanisms by using stress, strain, and deflection measurements. By gaining an understanding of how geogrids affect the load response of a pavement structure, it is possible to identify conditions for optimum reinforcement benefit as well as conditions for which grid reinforcement may not be as effective.

The major conclusions of the test program, which have been reported elsewhere (*2, 3*), follow:

1. Grid reinforcement can increase the number of load cycles carried by a factor of 3 (for a "failure" criterion of 0.8-in. permanent deformation, which is generally considered appropriate for high-type pavement facilities);
2. Base thickness reductions of 25 to 50 percent are made possible by inclusion of geogrids; and
3. The optimum location of grid reinforcement within the granular layer was found to be dependent on granular thickness and subgrade strength.

These conclusions suggest that the potential benefits of incorporating grid into a base layer are dependent on choosing the appropriate grid location because grid location can dramatically affect the load response of the pavement. Examination of stress, strain, and deflection data clearly indicates how geogrid reinforcement at the optimum location can effectively interlock with and confine an aggregate base, resulting in increased resistance to lateral and vertical deformation.

Stress Measurements

Pressure cells were placed 1½ in. below the top of the subgrade in selected test sections. In Loops 2 to 5, one pressure cell was placed directly beneath the load center and another at 12 in. radial distance from the load center. In Loop 6, one pressure cell was placed beneath the load center only in three of the four tests.

Pressures were monitored at predetermined cycle counts when dynamic loading was temporarily stopped. Readings

TABLE 2 TENSAR SS1 GEOGRID (BX1100)

Geogrid Property	Test Method	Unit	Value
Aperture size	I.D. calipered[a]		
MD (roll direction)[b]		in.	1 (nom.)[c]
CMD (across roll width)[d]		in.	1.3 (nom.)
Open area	COE method[e]	%	70 (min.)
Thickness	ASTM D 1777-64		
Rib		in.	0.03 (nom.)
Junction		in.	0.11 (nom.)
Flexural Rigidity	ASTM D 1388-64		
MD		mg·cm	250,000
CMD		mg·cm	325,000
Tensile modulus	ASTM D 638-82[f] (modified)		
MD		lb/ft	14,000 (min.)
CMD		lb/ft	20,000 (min.)
Junction strength	ASTM D 638-82[g]	%	90 (min.)

[a]Maximum inside dimension in each principal direction measured by calipers.
[b]MD = machine direction, which is along roll length.
[c]Nominal values that shall not vary by more than ± 15 percent.
[d]CMD = cross machine direction, which is across roll width.
[e]Percentage of open area measured without magnification by Corps of Engineers method as specified in CW 02215 Civil Works Construction Guide, November 1977.
[f]Secant modulus at 2 percent elongation measured by tensile loading test (ASTM D 638) modified to clamp single ribs of the grid structure at junctions and apply a constant rate of extension of the rib of 2 in./min at 68°F. No offset allowances are made in calculating secant modulus.
[g]ASTM D 638 modified to accommodate clamping of T-shaped junction and strained at 2 in./min (see TNN:PT2).

were taken using both 0- and 9,000-lb loads after a period of 3 min.

In Loop 2, it was observed that reinforcement at the base of the granular layer reduced the stress on the subgrade by approximately 22 to 23 percent from the first load application up to 10,000 cycles. Permanent deformations at the surface after 10,000 cycles were 0.8 and 0.46 in. for the control and reinforced sections, respectively. After 150,000 cycles the reduction in stress due to grid reinforcement was just 12 percent with deformations of 2.7 and 1.9 in., respectively. Although these deformations considerably surpassed the failure point (i.e., 0.8-in. permanent deformation) of both sections, the greater percentage reduction in stress in the control section can be attributed to shear failure of the asphalt concrete, base layer, and subgrade. Figure 2 shows the changes in subgrade stress with increasing load cycles.

In Loops 4 to 6, the subgrade strength was lowered to values of California bearing ratio (CBR) less than or equal to 1.0 by the addition of peat moss and moisture. However, given the physical constraints of the test facility, it was not possible to build pavement sections thick enough to be considered adequately designed for loads that would typically be carried by a highway pavement. Thus the final pavement sections tested, both with and without reinforcement, were underdesigned.

In contrast to the stress reductions that were observed in Loop 2 over a relatively weak subgrade, comparison of pressure cell readings in Loops 4 and 6 over very weak subgrades showed higher initial stresses (3 to 25 percent) in the subgrade beneath reinforced pavement sections changing to approximately equal stress values at the end of testing. Deformations at the end of testing were 1.9 in. (reinforced) and 2.4 in. (unreinforced) in Loop 4 and 1.8 in. (reinforced) and 2.3 in. (unreinforced) in Loop 6 after 10,000 cycles.

In summary, it was shown in Loop 2 that the grid contributed to a significant reduction in vertical stress on the subgrade, which suggests that the interaction of grid with the base course aggregate affects the distribution of stresses through the base layer of a low-deformation pavement and reduces the maximum vertical stress transmitted to the subgrade. On the other hand, the pavement sections of Loops 4 and 6 were so underdesigned that the grid was significantly stressed beyond its range of totally recoverable elastic response, and reductions in maximum stress were not initially apparent. In high-deformation structures, such as temporary haul roads, relatively large deformation occurred rapidly in both reinforced and control sections, and stresses on the subgrade were not reduced until tensioned membrane forces were taken up by the reinforcement. Thus, for grid reinforcement to be most effective, it is reasoned that the optimum location will be dictated by acceptable levels of stresses and strains within the grid itself.

Strain Measurements in Grid

Strain gauges were attached to the bottom side of the geogrid at various radial distances from the load center. As was the case with pressure cell measurements, strain readings were taken at predetermined cycle counts when dynamic loading was stopped. Comparison of strain data with performance criteria such as permanent deformations indicated that grids provided reinforcement benefit for low-

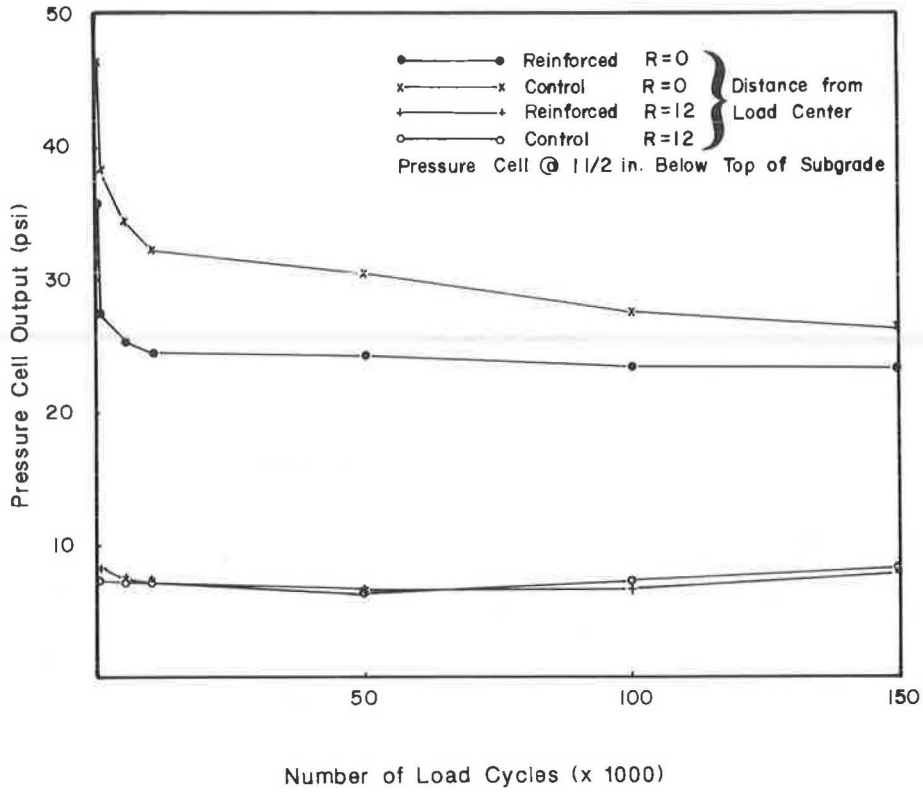

FIGURE 2 Pressure cell output versus load cycles, Loop 2.

deformation sections when initial elastic strain beneath the load center was less than or equal to 0.2 percent, provided that the grid was placed within the lower portion of the base layer. Under these ideal conditions, it was observed that elastic strain in the grid would decrease with increasing radial distance from the load center (Figure 3). At distances of 10 to 15 in. from the load center (approximately twice the radius of the load plate), small compressive values of strain were observed.

These results clearly illustrate the confinement effect of geogrids in the vicinity of the load. The grid is immediately mobilized to carry tensile stresses; long anchorage lengths

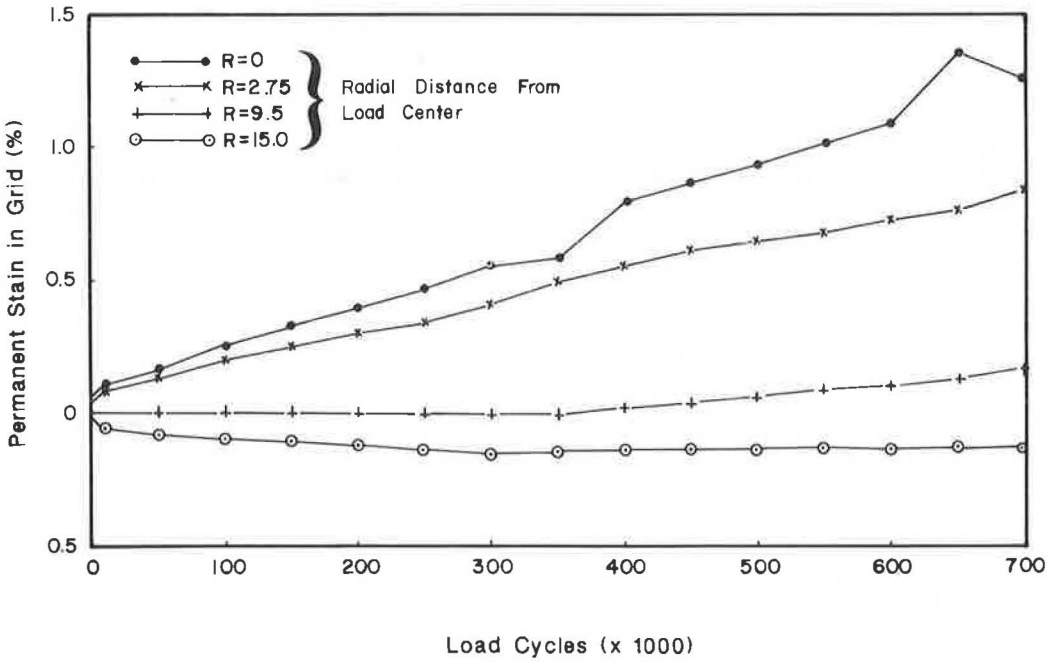

FIGURE 3 Permanent strains in grid versus load cycles: Loop 1, Test 2.

are not required, and large deformations do not have to occur.

As was the case with permanent deformations, plastic strain in the grid increased gradually with an increasing number of load cycles. Although the grid behaves elastically under moderate stress, these immeasurable plastic strains appeared to increase linearly with the number of load cycles, as shown in Figure 3. It was found that, at the failure level of 0.8-in. total deformation, plastic strains in the grid ranged from 1.0 to 1.8 percent in tests in which grid provided the most benefit (i.e., in the lower half of the base of structurally adequate pavements).

On the other hand, when grid was placed near the top of the base layer, no performance benefit was observed. Observation of both elastic and plastic strains revealed that both were initially very low. As the number of load cycles increased beyond 500, the grid went into compression beneath the load center until relatively large surface deformations occurred. These were in the order of 0.6 in. after 100,000 cycles. Thus the pavement section was approaching failure (i.e., 0.8 in.) before the grid began to take up tensile load. It was further noted that the grid was in tension 15 in. from the load center, suggesting that it was acting more independently to support load than when it was placed in the lower portion of the base.

As stated previously, Loops 4 to 6 were underdesigned for the soft subgrade conditions. This was also evidenced by the considerably higher elastic strains that were observed in the grid (i.e., 0.2 to 1.0 percent strain under the load center). Furthermore, high tensile strains were also noted at 9 and 14 in. from the load center in some cases. The higher strains away from the load center indicate that the grid was overstressed for its confinement function in a flexible pavement (i.e., it was being stretched more like a membrane). Thus the cumulative strain along the tensioned member resulted in the rapid occurrence of a permanent deformation of 0.8 in., which is similar to the deformation of the pavement section without reinforcement. However, it was found that the rate of deformation was less for the grid-reinforced test sections after the initial 0.8-in. deformation had occurred and that if a high value were chosen for the failure criterion (e.g., 1.5 in., which is used for lower-type paved roads) grid-reinforced sections again carried two to three times as many load cycles to failure.

The important finding here is that stress or strain levels for which grid reinforcement is most effective in flexible pavements can be quantified by stress-strain analysis and taken into consideration during design. Thus layered elastic theory can be used to design a pavement with geogrid reinforcement such that radial strains under the load center at the proposed grid location will fall within some limiting range, for example, 0.05 to 0.2 percent.

Deflection Measurements

In all tests five dial gauges were used in conjunction with the actuator LVDT to measure elastic deflection and permanent deformations at various locations along the asphalt surface. Two of the dial gauges were placed on the loading plate ½ in. in from the outside edge. Again, static readings were taken on all five gauges at predetermined cycle counts. In addition, dynamic deflections of the load plate itself were recorded by the actuator LVDT at the beginning and end of each series of dynamic loading.

Although it has been reported previously that geogrid reinforcement shows no appreciable reductions in static or dynamic deflections directly beneath the load, an examination of average static deflection readings in Loops 1 and 2 did indicate that the shape of the deflection basin was somewhat flatter for reinforced pavements than for control sections of equal thickness.

In Figure 4, average deflection values for the four tests of Loop 1 have been plotted at various distances from the load center. As can be seen, the two sections reinforced with grid in the lower half of the base layer show consistently lower values for elastic deflection, particularly at the critical location near the edge of the load plate. This implies that the base course of the reinforced section is stiffer (i.e., has a higher elastic modulus) and is indeed yielding less than the control section at the edges of the plate. In other words, the cantilevered portion of the 1-in.-thick plate bends more in the reinforced tests.

The vertical scale of Figure 4 is, of course, considerably exaggerated compared with the horizontal scale. This is normal practice in the pavement engineering field, particularly for field measurements during which deflection bowls measured by such devices as the Dynaflect or Falling Weight Deflectometer are plotted to a much exaggerated vertical scale. The purpose is to more clearly illustrate differences that may be small in absolute magnitude but highly significant with regard to behavior of the pavement structure.

Figure 4 also shows that elastic deflections in the section with grid near the surface of the base were considerably greater than those in the control section, although the shapes of the two deflection bowls are fairly similar. This indicates that placing the grid near the surface of the base does not provide much confining or stiffening effect.

Because of the soft subgrade conditions of Loops 4 to 6, static deflections were excessive for higher-type flexible pavements, ranging from approximately 0.2 to 0.6 in. under the load center. Nevertheless, the data still provided useful information about optimum location and limitations of grid reinforcement in high-deformation structures. For example, in Loop 4, the plate deflections were reduced by approximately 17 percent at cycles 1 and 20,000 when grid was placed at the bottom of an 8-in. base layer, as shown in Figure 5. Again, it was observed that the angle of curvature of the deflection basin was reduced in the grid section. The resultant permanent deformations at the surface after 20,000 load cycles were 1.794 and 2.371 in. for the reinforced and control sections, respectively, or a 25 percent reduction in rut depth.

On the other hand, when grid was placed at the midpoint of a 12-in. base layer over the weakest subgrade of all, Loop 6, it was found that deflections of the load plate were significantly less in the control section although the shape

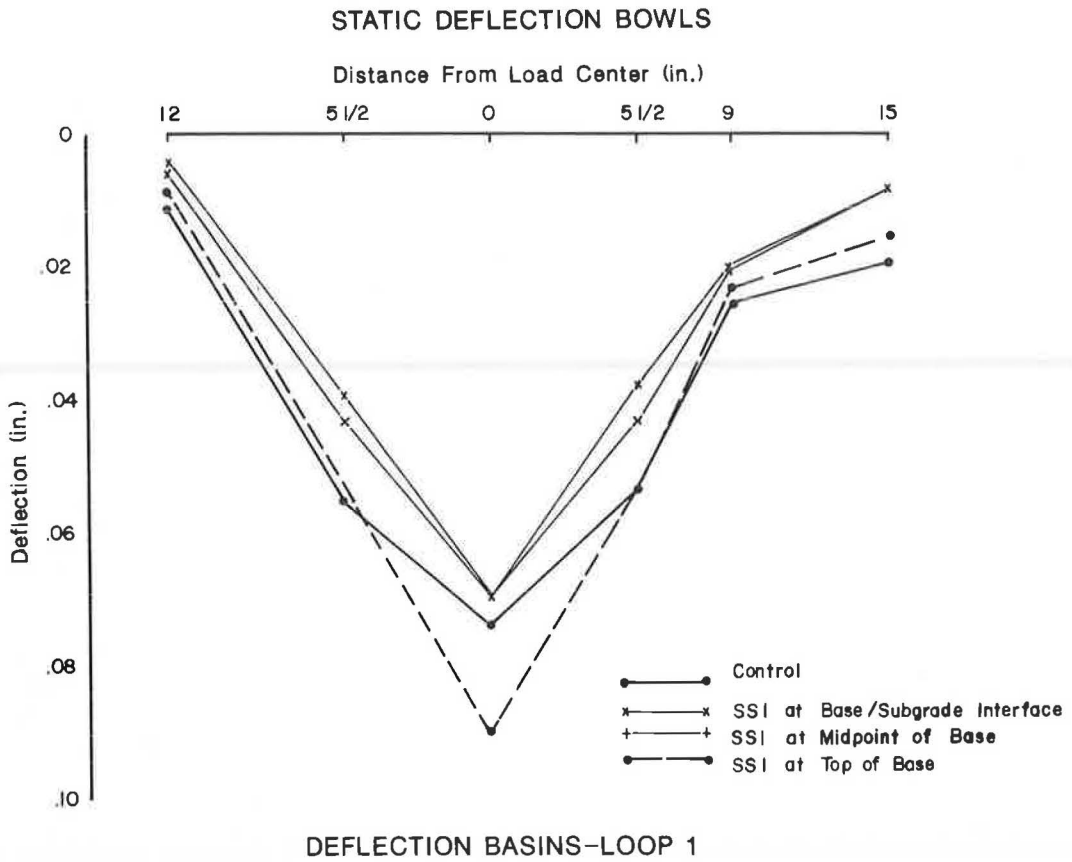

FIGURE 4 Deflection basins, Loop 1.

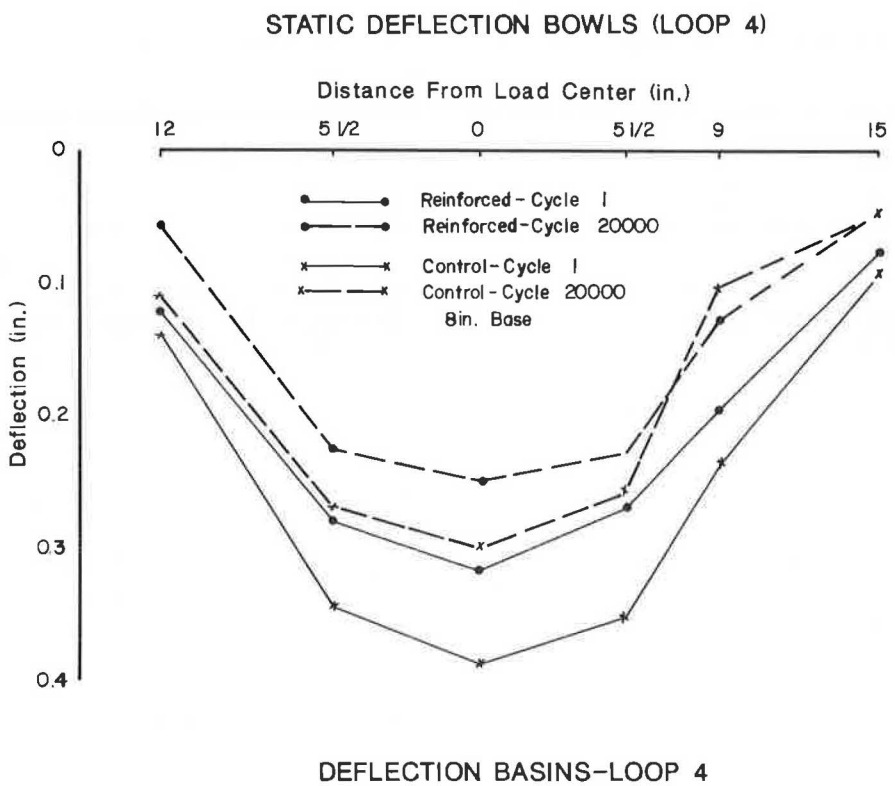

FIGURE 5 Deflection basins, Loop 4.

of the deflection basins was approximately the same. Permanent deformations at the surface after 40,000 cycles were 1.67 and 1.68 in. for the reinforced and control sections, respectively, indicating no benefit from grid under the conditions of the test. This finding is consistent with the results of another test program on grid reinforcement of granular base over peat carried out at the Royal Military College (RMC) of Canada. It was found in the RMC study that grid reinforcement at the midpoint of a 12-in. granular base did not provide any improved rutting resistance under load until permanent deformations were quite large (i.e., on the order of 6 to 8 in.). In addition, there was no appreciable decrease in static deflections. When the granular base was removed, it was found that aggregate had punched into the peat in a manner similar to that observed on the unreinforced section. However, when placed at the bottom of the base layer, geogrid reinforcement significantly reduced rutting, subgrade deformation was more gradual and widespread, and little or no punching of aggregate into the peat occurred. This last observation suggests that the grid can be an effective separator, if placed at the interface.

CONCLUSIONS

Through analysis of stress, strain, and deflection data, it has been shown that grid reinforcement does alter distribution of load-induced stresses in flexible pavements. The result is that the rate of permanent deformation (rutting) can be decreased and pavement life can be extended. However, it has also been shown that conditions exist for which grid reinforcement does not offer performance benefits. The key to optimizing geogrid potential is proper design. Proper design requires appropriate layer thicknesses and selection of optimum geogrid location.

For thin bases, the optimum grid location is usually considered to be at the base-subgrade interface. However, for thicker bases, there is sufficient evidence to suggest that the optimum location is in the middle portion. No benefits are expected when a single layer of grid is placed within a zone of compression, such as

- Near the top of the base layer under an asphalt concrete surface or
- Within the base layer (e.g., midpoint or higher) of thick bases over very soft flexible subgrades.

In the second case, it has also been found through field experience that geogrid reinforcement at the base-subgrade interface over soft, flexible subgrades segregates the layers and facilitates construction of a stiffer base using less material. If the base is very thick, a second layer of geogrid may be placed at some middle location to retard the rate of permanent deformation within the base itself.

In summary, for optimum grid reinforcement of flexible pavements, the grid must be placed in a zone of moderate elastic tensile strain (i.e., 0.05 to 0.2 percent) beneath the load center, and maximum permanent strain in the grid over the design life should not exceed 1 to 2 percent, depending on the rut depth failure criteria. Under these ideal conditions, grid reinforcement behaves elastically and effectively confines aggregate base, thus prolonging the life of the pavement structure.

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