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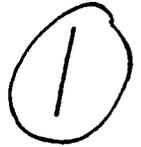


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Research and  
Development Service  
Washington, D.C. 20591

**Geogrid Reinforced Base Course  
For Flexible Pavements For Light  
Aircraft:**

**Literature Review and Test  
Section Design**



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**SELECTE**  
**S D D**  
AUG 14 1991

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May 1991  
Interim Report

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16. Abstract <p>This report presents the results of a literature review investigating geogrid reinforced base courses for flexible pavements for light aircraft and the design of a geogrid test section for field testing the validity of potential geogrid reinforcement results.</p> <p>The literature review included related areas such as geogrid ballast reinforcement for railroad track bed, reinforcement for aggregate surfaced pavements, and reinforcement for flexible pavements.</p> <p>Based on the literature review, geogrids have application in ballast reinforcement for railroad track bed and in reinforcement for aggregate surfaced pavements. Full-scale field tests have verified that for subgrade CBR strengths of 1.5 to 5.0, geogrid reinforced aggregate surfaced pavements can carry about 3.5 times more traffic repetitions than equivalent nonreinforced pavements before a 1.5-in. rut depth is reached.</p> <p style="text-align: center;">(Continued)</p>					
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16. ABSTRACT (Concluded).

The improvement mechanisms for geogrid, reinforced aggregate layers, are known and both laboratory and analytical studies indicated that geogrid reinforcement of aggregate bases can improve flexible pavements performance.

Geogrids perform better than geotextiles in base layer reinforcement mainly because of grid interlock with aggregate particles. Poor friction properties of geotextiles do not allow good interlock with aggregate particles.

A test section design is presented that will validate, through full-scale traffic tests, the geogrid base reinforcement potential for flexible pavements for light aircraft. Results of the traffic tests on this test section will be reported later.



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## METRIC CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO METRIC MEASURES

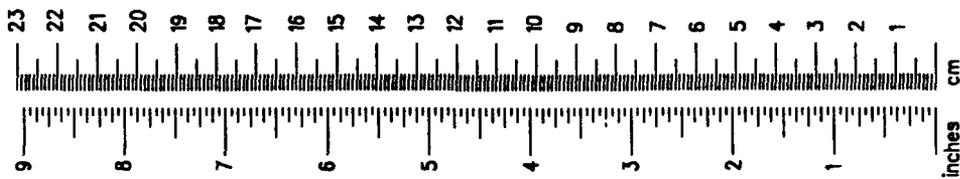
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
in.	inches	2.54	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hactares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>

#### TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
		C-5/9(F-32)		

### APPROXIMATE CONVERSIONS TO ENGLISH MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in.
cm	centimeters	0.4	inches	in.
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.8	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hactares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (weight)</b>				
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
		F-9/5C+32		



## PREFACE

The information reported herein was sponsored by the US Department of Transportation, Federal Aviation Administration (FAA) under Interagency Agreement No. DTFA01-89-Z-02029, "Grid Reinforced Aggregate Base Courses for General Aviation Airports." This report is an interim report covering a literature review and field test section design on geogrid reinforced base courses for flexible pavements for light aircraft. A second interim report covering results of geogrid traffic and laboratory tests will follow. A final report covering geogrid design criteria will be written to complete the agreement. Technical Monitor for this study was Mr. Hisao Tomita.

This study was conducted from March to October 1990 under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES). Direct supervision was provided by Mr. H. H. Ulery, Jr., Chief, Pavement Systems Division (PSD) and Dr. A. J. Bush, Jr., Chief, Criteria Development and Applications Branch (CD&AB), PSD. This report was prepared by Mr. S. L. Webster, CD&AD, PSD.

Colonel Larry B. Fulton, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was the Technical Director.

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## INTRODUCTION

### BACKGROUND

Geosynthetics is the generic term for all synthetic materials used in geotechnical engineering applications. It includes geotextiles, geogrids, geonets, geomembranes, geocell, and geocomposites. Koerner<sup>(21)</sup> defines these products as follows:

a. Geotextile. Any permeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system.

b. Geogrid. A deformed or nondeformed grid-like polymeric material formed by intersecting ribs joined at the junctions used for reinforcement with foundations, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system.

c. Geonet. A net-like polymeric material formed from intersecting ribs integrally joined at the junctions used for drainage with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system.

d. Geomembrane. An essentially impermeable membrane used as a liquid or vapor barrier with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system.

e. Geocell. A three-dimensional structure filled with soil, thereby forming a mattress for increased bearing capacity and maneuverability on loose or compressible subsoils.

f. Geocomposite. A manufactured material using geotextiles, geogrids, geonets, and/or geomembranes in laminated or composite form.

Geosynthetic materials perform five major functions in civil engineering applications: separation, reinforcement, filtration, drainage, and moisture barrier. The geogrids described in this report represent a small but rapidly growing segment of the geosynthetics area. Geogrids are relatively stiff, net-like materials with large open spaces called apertures, which are typically 0.5 to 4.0 in.\* between the ribs. The ribs themselves can be fabricated from a number of different materials, and the rib crossover joining or junction-bonding methods can vary. The primary function of geogrids is reinforcement. Geogrids were introduced to the North America market in 1982. Currently, at least six companies are marketing geogrids, and others are developing geogrid products. Major reinforcement applications include ballast for railroad track bed, aggregate-surfaced pavements, flexible pavements,

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\* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page iii.

embankments, slopes, and walls. Figure 1 shows typical types of geogrids used for base course applications.

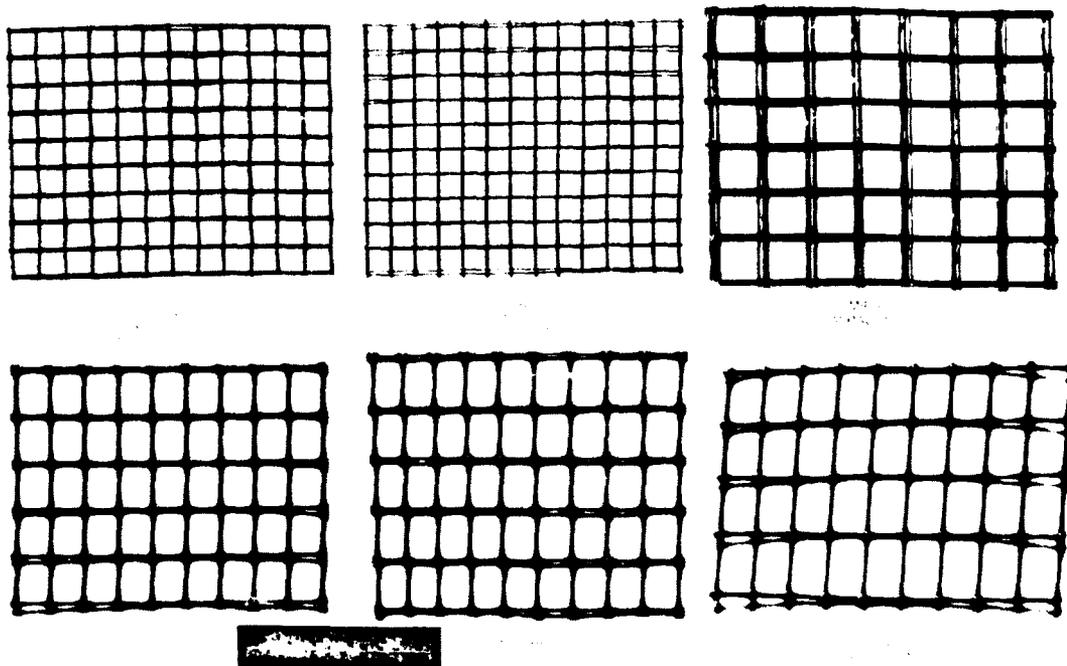


Figure 1. Typical geogrids for base course reinforcement applications

#### PURPOSE

The purposes of this report are to present (1) the results of a literature review investigating the potential for geogrid reinforced base courses for flexible pavements for light aircraft (gross aircraft weight not exceeding 30,000 lb) and (2) the design of experiments for field testing the validity of the potential geogrid light airfield pavement base course reinforcement.

#### SCOPE

Only the first phase results are presented in this report. The scope of this phase of the investigation includes a literature review of geogrids in general, their reinforcement applications in railroad tracks, aggregate surfaced pavements, and flexible pavements. Included in the review are small-scale and large-scale laboratory tests, analytical studies, and full-scale field tests. Based on the information learned, a full-scale field test section was designed to test geogrid reinforcement potential for use in flexible pavements for light aircraft. The field test section design included various

types of geogrid products. Performance results for each type of geogrid will be required for preparation of generic specifications and design for geogrids.

Based upon FAA approval of the full-scale test section design, in a second phase, the test section will be constructed and subjected to full-scale traffic tests. In addition, laboratory tests on various geogrid materials will be conducted to determine the strength and other properties associated with each type of material. The results of all work will be reported to the FAA in an interim technical report outlining the activities, findings, and conclusions.

Based on the results of the above work, in the third phase of the study, a mechanistically based design criteria and construction procedures, for geogrid-reinforced base courses suitable for use by civil aviation utility airports, will be developed. Also, equivalent thickness tables for reinforced and nonreinforced systems will be prepared. The results of this work will be included in a second technical report to the FAA.

## LITERATURE REVIEW

The scope of the literature review was limited to geogrids in general and their use in pavement base reinforcement applications to include railroads, aggregate surfaced pavements, and flexible pavements. The study was limited to biaxial geogrid products designed for pavement type applications. The study did not include the uniaxial geogrid products designed for one directional in-plane loadings for walls, embankments, or slope applications in which the major principal stress direction is known.

Table 1 lists the geogrid products available for flexible pavement base reinforcement applications as of December 1989.<sup>(27)</sup> Many additional geogrid products are available for other reinforcement applications including aggregate rafts, slopes, walls, asphalt, and other bases. The physical and mechanical properties of these products vary substantially. The polymer composition of the various products for flexible pavement base reinforcement includes polypropylene and coated polyester. The structures are either woven or formed by prepunched sheets that are drawn mechanically or by rolling. The mass per unit area varies from 5.5 to 11.5 oz/sq yd. The aperture size ranges from 0.69 to 1.8 in. The wide-width tensile properties using ASTM Test Method D 4595-86 yields a wide range of tensile strengths for the geogrid products. A strain level of 5 percent has gained some degree of acceptance for most pavement reinforcement applications<sup>(2)</sup>. The 5 percent secant modulus (tensile load at 5 percent strain divided by 5 percent) ranges from 420 lb/in. to 2,340 lb/in. for the available geogrids listed in Table 1. Barksdale, Brown, and Chan<sup>(2)</sup> call the secant modulus (used in ASTM Test Method D 4595-86) the secant geosynthetic stiffness and found that the stiffness is the most important variable associated with base reinforcement that can be readily controlled. Their research utilized analytical sensitivity studies of the influence due to reinforcement of pertinent variables on pavement performance and large-scale laboratory tests with rolling wheel loads on various pavement test sections. Their experimental results indicated that a geogrid having an open mesh has the reinforcing capability of a woven geotextile having a stiffness of approximately 2.5 times as great as the geogrid. Therefore, using a geogrid having a stiffness (5 percent secant modulus) of 1,500 lb/in. for aggregate base reinforcement would be equivalent to using a woven geotextile having a stiffness of 4,000 lb/in.

Important criteria when considering geogrids for aggregate base reinforcement include the following:<sup>(2,7,20,22)</sup>

- a. Geometry.
  - (1) Aperture size.
  - (2) Percent open area.
  - (3) Ratio of minimum aperture width to average (aggregate size).
- b. Mechanical Properties.
  - (1) Tensile strength/elongation (5 percent secant modulus).
  - (2) Junction (node) strength.

Table 1  
Geogrid Products Available for Flexible Pavement Base Reinforcement Applications<sup>(1)</sup>

Product Name	Structure	Polymer Composition	Junction Method	Cost \$/sq yd	Dimensional Properties		5 percent Secant Modulus**	
					Mass/Unit Area* oz/sq yd	Aperture Size in.	MD lb/in.	XMD lb/in.
SS-1	Punched Sheet-Drawn	Polypropylene	Planar	1.69	6.4	1.0 x 1.3	950	1,470
SS-2	Punched Sheet-Drawn	Polypropylene	Planar	2.95	9.0	1.0 x 1.3	1,170	2,000
FX-1500/ Fortrac20/13-20	Woven	Polyester/ PVC Coating	Interwoven	--	5.5	0.9 x 0.9	920	420
FX-3000/ Fortrac35/20-20	Woven	Polyester/ PVC Coating	Interwoven	3.00	9.0	0.9 x 0.9	1,840	840
FX-4000/ Fortrac55/30-20	Woven	Polyester/ PVC Coating	Interwoven	--	11.5	0.9 x 0.9	2,340	1,000
Miragrid 5T	Woven	Polyester	Knitted/ Coated	5.15	8.0	1.2 x 1.3	1,300	710
LB0201/AMP	Bi-oriented	Polypropylene	Extruded	1.50	5.9	1.8 x 1.7	920	1,250
GB-3022	Woven	Polyester/ PVC Coating	Interwoven	3.40	5.7	0.69 x 0.75	1,250	920

\* ASTM D 3776-84.  
 \*\* ASTM D 4595-86.

- c. Soil/Geogrid/Aggregate Interaction.
  - (1) Shear strength.
  - (2) Anchorage strength.
- d. Endurance Properties.
  - (1) Creep resistance.
  - (2) Installation damage.
- e. Environmental Properties.
  - (1) Chemical effects.
  - (2) Biological effects.
  - (3) Temperature effects.
  - (4) Weathering resistance.
  - (5) Stress cracking.
- f. Geogrid Placement Location.

#### LITERATURE ON AIRFIELD APPLICATIONS

Only one reference, Barker<sup>(1)</sup>, was found in the literature involving the use of geogrids and flexible pavements for airfields. No other literature was found involving the use of geogrids and aggregate surfaced airfields or traffic tests with aircraft type wheel loadings. A brief description of Barker's work is included in the section "REINFORCEMENT FOR FLEXIBLE PAVEMENTS". Based on the very limited literature available on geogrid applications in airfield pavements, the literature review was expanded to cover railroad and both aggregate surfaced and flexible pavements for roads. The results of this literature review follows.

#### BALLAST REINFORCEMENT FOR RAILROAD TRACK BED

A substantial amount of the geogrid reinforcement research and laboratory testing that has been conducted was geared toward ballast for railroad track bed applications.<sup>(4,5,6,11,12,13,14,15,26,28,29,30,37)</sup> Most of this work was performed by the Royal Military College in Canada and Queens University at Kingston, Ontario, Canada. A literature review on the use of geogrids in ballast reinforcement for railroad track bed was recently completed by Coleman<sup>(11)</sup> with the following conclusions.

a. When placed in (or between) the ballast, subballast, and/or subgrade layers of a railroad track, geogrids perform one or more of the following functions: provide lateral and vertical restraint to confine the ballast and resist decompaction, separate dissimilar materials, provide a working platform over very soft subgrade soils, and provide a membrane support by going into tension at relatively low strain levels.

b. Provision of lateral and vertical support most likely comes from particles of granular material becoming wedged in the apertures of the geogrid, increasing the tensile strength and frictional resistance of the granular material. This lateral and vertical support will assist in reducing the permanent deformation that occurs in track and may assist in reducing track maintenance requirements.

c. Separation of dissimilar materials only occurs when the materials being separated are larger than the apertures in the geogrids.

d. Over very soft subgrades where there is a need to construct a working platform in order to achieve adequate compaction of a subballast or other granular material, a geogrid will be beneficial in reducing the amount of subballast required to construct this working platform and support subsequent construction traffic.

e. Geogrids will provide some reinforcement of granular materials by going into tension at relatively low strain levels. However, in many cases this beneficial tensile strength is motivated only after large deformations of the system have occurred. In an in-service railroad track the amount of deformation required to motivate this tensile strength may be unacceptable.

f. It is believed that the presence of a geogrid in the ballast or subballast will reduce the magnitude of the vertical stress acting on the subgrade. However, laboratory and field tests have not quantified the amount of pressure reduction that can be expected. It is thought that this pressure reduction will not be significant at normal railroad operating loads with reasonable subgrade strengths. However, as the applied vertical pressure approaches the bearing capacity of the soil, the greater the influence of the geogrid will be in improving the subgrade bearing capacity.

g. The ballast/subballast thickness, as determined from conventional design procedures, required to support railroad wheel loadings cannot be reduced by the use of a geogrid in the granular layer. There are no laboratory tests or field experience to support such reductions.

h. Geogrids are beneficial and their use may be justified in site-specific locations to provide a working platform or reinforce track over very weak subgrade soils or other problem locations. However, geogrids should not be specified for wholesale use in the construction/reconstruction of railroad track over reasonably competent subgrades, as there is not technical or economical justification for this practice.

#### REINFORCEMENT FOR AGGREGATE SURFACED PAVEMENTS

A total of 10 references<sup>(3,9,16,17,19,23,24,35,36,38)</sup> were reviewed concerning the use of geogrids as reinforcement for aggregate surfaced pavements.

a. Plate-Load Tests on Geogrid Reinforced Sand. Guido, Knueppel, and Sweeny<sup>(17)</sup> conducted laboratory model plate loading tests to study the bearing capacity of geogrid reinforced uniformly graded sand (SP). A 12-in. square load plate, three types of geogrid, and various numbers of layers of geogrid reinforcement were used. Results indicated that geogrid reinforcement increased the ultimate bearing capacity of the nonreinforced sand by a factor of 3 when geogrid was optimally placed in layers. Results also indicated that instead of using fewer stronger (stiffer) ribs, the use of many weaker ribs provided a better distribution of the tensile stress to the geogrid. Based on plate-load and pull-out tests, it was concluded that sand-geogrid bond

performance was greatly dependent upon the amount of geogrid lateral bearing area available to the sand.

b. Plate-Load Tests on Geogrid Reinforced Aggregate Layers over Weak Clay Subgrades. Milligan and Love<sup>(25)</sup> conducted small-scale laboratory model tests under plane strain conditions by applying monotonic loading from a rigid strip footing to reinforced and nonreinforced soil-aggregate systems, using a range of aggregate thicknesses and clay subgrade strengths. Performance of the reinforced systems was significantly better. The increased performance resulted from the reinforcing action of the geogrid, which interlocks with the granular base material and resists tensile strains which develop at the base of the aggregate layer. In the tests, the failure load was defined as the load at which displacement started to increase rapidly (approximately five times the undrained shear strength). Failure loads for the geogrid reinforced systems were typically about 40 percent higher than for nonreinforced systems. It was also noted that for loads up to about 50 percent of the failure load for the nonreinforced systems, there was very little difference in performance between the reinforced and unreinforced systems. For higher loads the stiffness of the nonreinforced system reduces quite rapidly as plastic flow begins to occur in the subgrade.

Milligan, Fannin, and Farrar<sup>(24)</sup> conducted full-scale laboratory tests using rectangular and circular footings, two weak clay subgrade strengths (CBR 1-1.5 and CBR < 0.4), one type reinforcement geogrid, static loading, and various aggregate layer thicknesses. The basic conclusion was that geogrid reinforcement placed at the interface of base aggregate and subgrade surface was equivalent to an increase of 2 in. of thickness of base layer for a given deformation of 1.5 in. Results also suggested a number of situations in which a geogrid could be more effective.

- (1) Geogrid reinforcement would be more effective in less stiff granular materials (marginal base course materials).
- (2) Geogrid reinforcement is more effective at large deformations, as might occur in temporary roads.
- (3) Further improvement could be achieved by optimum location of the geogrid and by geogrid properties that ensure interlock between geogrid and aggregate particles.

c. Plate-Load Test on Geogrid Reinforced Aggregate Layers over Peat Subgrades. Jarrett<sup>(19)</sup> and Bathurst and Jarrett<sup>(3)</sup> conducted both static and cyclic load tests on geogrid reinforced gravel fills constructed on peat subgrades. The gravel fill thicknesses varied from 6 to 18 in. and were tested with and without geogrid reinforcement. For the test, an 8-in.-wide beam which spanned the full 94-in.-wide test pit was pushed into the gravel under a series of incrementally increasing loads. Results indicated little difference between the reinforced and nonreinforced gravel occurred until beam displacements of 1.5 to 2 in. were reached. At large displacements of 8 in., significant reinforcement was being most effectively mobilized as a tensioned membrane.

d. Aggregate Surfaced Pavement Design Using Geogrids. Giroud, Ah-Line and Bonaparte<sup>(16)</sup> present an initial development of a design method for geogrid-reinforced aggregate surfaced structures. The design method presented includes several mechanisms by which geogrids can improve unpaved structure behavior. The following improvement mechanisms are the most significant:

(1) Subgrade Confinement. When the vertical stress on the subgrade soil exceeds the elastic limit, local shear failure and large deformations ensue. These large deformations result in accelerated deterioration of the base layer and fatigue of the subgrade soil, causing the subgrade soil to be subjected to even higher stress levels. Consequently, after small amounts of additional traffic the ultimate bearing capacity of the subgrade is exceeded, and general shear failure occurs. If the subgrade soil is confined by the continuity of a reinforcing element (geotextile or geogrid), deformations resulting from local shear failure do not become large, and the subgrade soil can support a vertical stress close to its ultimate bearing capacity.

(2) Grid Interlock with Aggregate Base Material. By interlocking with the base layer aggregate, geogrids reduce permanent lateral displacements which accumulate with increasing numbers of load repetitions. Reduced displacements result in reduced deterioration of base layer material properties while preserving the effective thickness of the base layer. Work by others has shown that the optimum placement depth of the geogrid should be in the range of 0.3 to 0.6 times the load width. Geotextiles, in general, do not provide good interlock capabilities.

(3) Separation. Separation of the base layer and subgrade soil (by geotextiles or, in some cases, geogrids), prevents aggregate contamination and aggregate sinking. Separation, therefore, reduces degradation of the mechanical properties of the aggregate and helps maintain the thickness of the base layer.

(4) Tensioned Membrane Effect. If the subgrade soil is incompressible (such as saturated clay), deformation of the subgrade soil under the wheels causes heave between and beyond the wheels. Therefore, the geogrid (or geotextile) exhibits a wavy shape. Consequently, it is stretched. When a stretched flexible material has a curved shape, normal stress against its concave face is higher than normal stress against its convex face. This is known as the "tensioned membrane effect". Tensioned membrane effect results in confinement of the subgrade and a reduction of the stress applied by the wheel on the subgrade.

Calculations presented show that geogrids can provide significant improvement in base layer load distribution capability. The thickness of nonreinforced aggregate surfaced structures can be reduced by 30 to 50 percent by using geogrids. Approximately half the thickness reduction resulting from geogrid reinforcement is due to subgrade confinement, and approximately half is due to improved load distribution resulting from geogrid-base layer material interlocking. The reductions in design thickness resulting from the tensioned membrane effect are negligible for a 3-in. rut-depth failure criteria. For a 6-in. rut-depth failure criteria, a lump reduction in design thickness of 10 percent is recommended for the tensioned membrane effect. The

design procedure presented should be considered with caution because the method has not been calibrated with either small-scale or full-scale test data.

The Tensar Corporation<sup>(34)</sup> provides design guidelines for haul and access roads reinforced with their geogrids. The design guidelines are based on charts developed by the US Forest Service for logging roads. An additional chart is then used to determine the base thickness for unpaved roads using the Tensar geogrid. A base thickness reduction of approximately 40 percent is obtained using geogrid reinforcement.

d. Full-Scale Traffic Tests on Geogrid Reinforced Aggregate Layers over Weak Clay Subgrades. The 1990 Specifier's Guide<sup>(27)</sup> conducted truck traffic tests on geogrid reinforced base layers over weak clay subgrades. Three subgrade strengths (CBR 4.9, 1.6, 0.4) and wedge shaped aggregate base layers (with aggregate thicknesses varying along the test lane profile from 6-11-in., 8-16-in., and 18-23-in.) were tested. Each test lane contained a nonreinforced and a geogrid reinforced section. Only one geogrid material was used. The geogrid was placed between the aggregate base and subgrade surface. Traffic was applied using a truck having a dual-wheel rear axle loaded to 18 kips. As traffic progressed the rear axle load was increased to 29 kips. Up to 1,300 traffic passes were applied to each test lane. Conclusions from the tests were as follows:

(1) For the same thickness of aggregate base on a subgrade of CBR strengths of 1.5 to 5.0, geogrid reinforcement between the aggregate base and subgrade surface allowed about 3.5 times more traffic to be carried before the deformation at the surface of the aggregate base reached 1.5 in. Alternatively, the same performance under traffic would be obtained if the reinforced base layer was 2 in. thinner than the corresponding nonreinforced structure.

(2) Little reinforcement of the base layer occurred over the CBR 0.4 subgrade. Clay particles had extruded through the apertures of the geogrid and prevented good grid interlock with particles base layer aggregate. More effective performance would probably have occurred if some base layer material had been placed on the subgrade prior to laying the geogrid.

e. Full-Scale Traffic Tests on Geogrid and Geotextile Reinforced Aggregate Layers over a Sand (SP) Subgrade. Webster<sup>(38)</sup> conducted truck, tank, and C-130 aircraft-tire traffic tests on geogrid and geotextile reinforced aggregate layers on a sand (SP) subgrade. The tests included a 4-in. aggregate base layer with and without reinforcement placed at the top of the subgrade. Reinforcement materials were as follows:

Test <sup>1</sup> Item	Reinforcement	Wide Width Strength/ Elongation ASTM D 4595-86 lb/in. @ 5% Strain	Grab Strength/ Elongation ASTM D 4632-86 lb/%
1	None	--	--
2	Geotextile	--	130/60
3	Geogrid	47.4	--

Test <sup>1</sup> Item	Reinforcement	Wide Width Strength/ Elongation ASTM D 4595-86 lb/in. @ 5% Strain	Grab Strength/ Elongation ASTM D 4632-86 lb/%
4	Geotextile	--	250/20
5	Geotextile	--	475/25
6	Geotextile	--	1,000/25

Test traffic loads were as follows:

Truck	C-130	Tank
5 ton military Payload at 20,000 lb Guess weight at 41,900 lb Tire pressure at 70 psi	Single tire Load at 35,000 lb -- Tire pressure at 100 psi	70 ton vehicle -- -- --

<sup>1</sup>See legend in Figures 2, 3, and 4.

Results of traffic tests are shown in Figures 2 through 4. Under truck traffic (Figure 2), only the geogrid item (Item 3) performed better than the control item (Item 1). For a 2-in. rut depth, the control item had 2,600 passes versus 5,200 passes for the geogrid item. Three geotextile items (Items 2,5,6) performed significantly worse than the control item. Photographs and cross section level measurements showed that the aggregate had moved laterally on the geotextiles. Under C-130 tire traffic (Figure 3), all reinforcement items surprisingly performed much worse than the control item. For a 3-in. rut, the reinforcement items handled only 100 to 200 passes while the control item had 600 passes. Under tank traffic (Figure 4), performance was mixed. The geogrid (Item 3) performed best, followed by the two strongest geotextiles (Items 5 and 6), the control (Item 1), and then the two weaker geotextiles (Items 2 and 4). For all three types of traffic, test results showed that geogrids perform better than geotextiles. Results of photographs and cross section level measurements indicated that reinforcement material friction properties are critical to performance and that more work needs to be done regarding placement depths of reinforcement materials.

#### REINFORCEMENT FOR FLEXIBLE PAVEMENTS

A total of 10 references<sup>(1,2,8,10,18,25,31,32,33,34)</sup> were reviewed concerning the use of geogrids as reinforcement for flexible pavements.

a. Plate-Load Tests on Geogrid Reinforced Base Layers for Flexible Pavements. A comprehensive laboratory research program to investigate geogrid reinforcement of granular base layers was carried out at the University of Waterloo in 1984<sup>(8,18,34)</sup> under the sponsorship of Tensar Corporation. The program consisted of repeated load tests on varying thicknesses of reinforced and nonreinforced granular bases. The reinforcement material was Tensar SS1

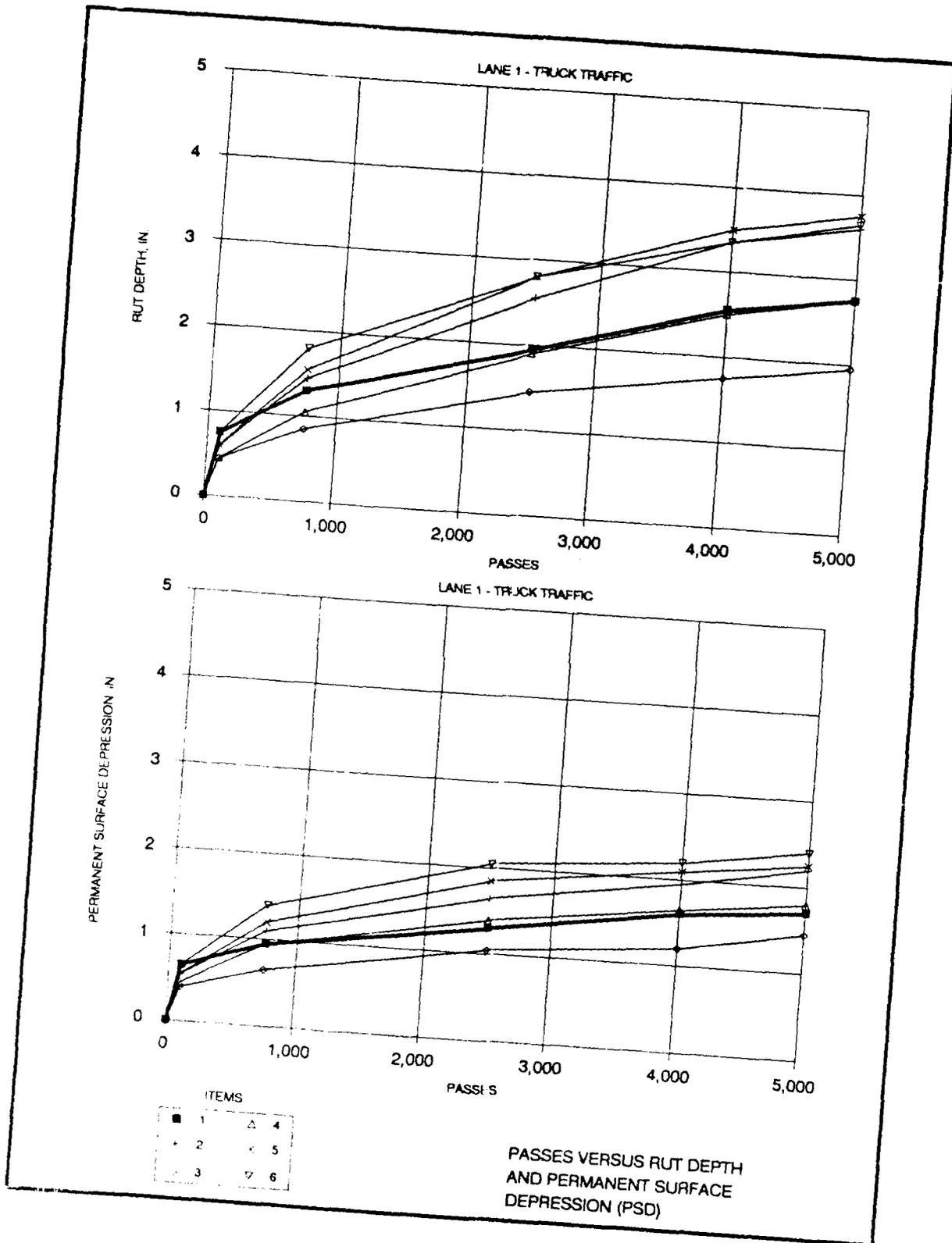


Figure 2. Truck traffic

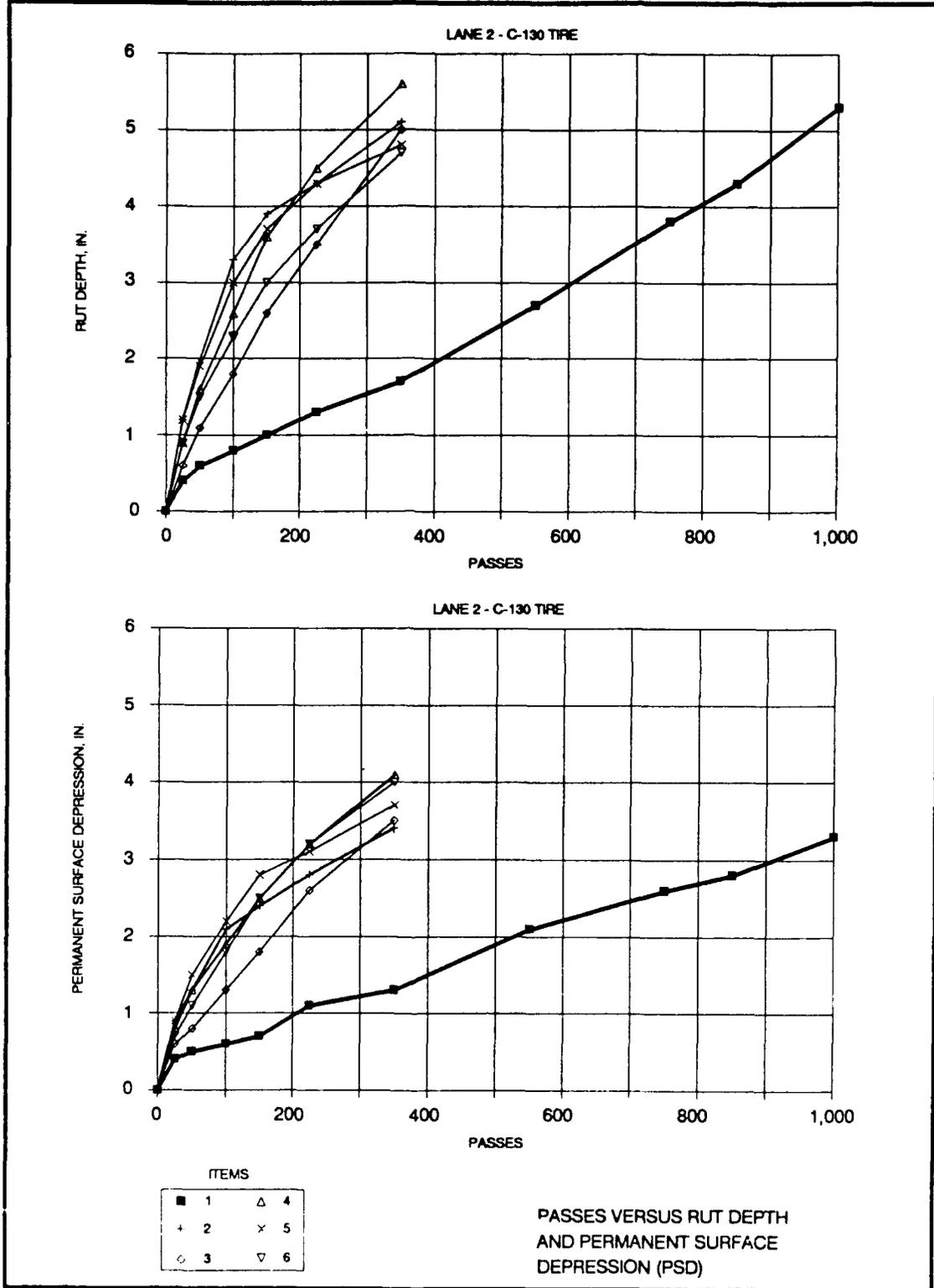


Figure 3. C-130 tire traffic

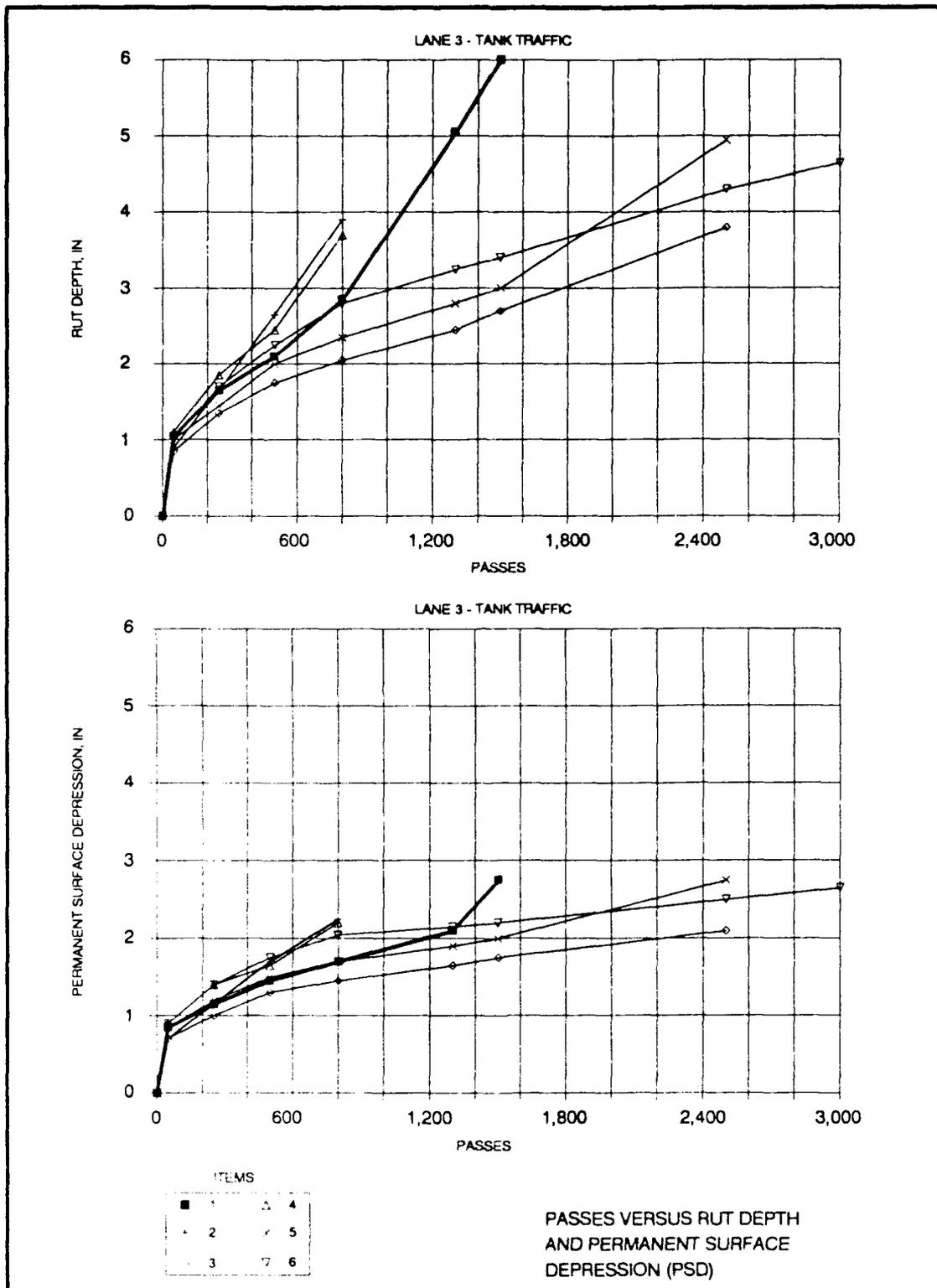


Figure 4. Tank traffic

geogrid. Other controlled variables included reinforcement location and subgrade strength. The program was divided into six test series with each containing four test items. The subgrade was a fine grained beach sand (SP). The sand subgrade was dry for test series 1 and saturated to lower its support strength in test series 2 and 3. An even weaker subgrade condition was created for test series 4, 5, and 6 by mixing peat moss into the top 8 in. of the sand. Asphalt concrete surfaces 3 to 4 in. thick were used in all tests.

A 9,000-lb load was applied to the pavement through a 12-in.-diam plate producing an applied pressure of 80 psi. Each test section was subjected to a sequence of cyclic loads (8 cycles per sec) followed by a single static load. Failure criteria were the development of 0.8-in. permanent deformation. The major conclusions of the test program were:

(1) Geogrid reinforcement reduces permanent deformation in flexible pavement systems.

(2) Pavement sections having geogrid reinforced base layers carried three times the number of load applications than the nonreinforced pavement sections before developing 0.8-in. permanent deformation under the 12-in.-diam plate.

(3) Geogrid reinforcement allowed up to a 50 percent reduction in the thickness requirements for granular base courses based on load-deformation performance.

(4) The optimum location of geogrid reinforcement within a base course layer is dependent upon the thickness of the base course and the strength of the subgrade. In general, the optimum location for reinforcement is at the bottom of thin base courses and at the midpoint of bases 10 in. thick or greater. On very weak subgrades the optimum benefit may be obtained by placing one layer of geogrid at the bottom of the base and a second layer at the midpoint of the base course. No benefits are expected when a single layer of geogrid is placed within the zone of compression, (i.e. near the top of the base course under an asphalt surface or near the top of a thick base course layer over very soft subgrades).

b. Small-Scale Plate Load and Full-Scale Road Tests of Geogrid Reinforced Base Courses for Flexible Pavements over a Clay Subgrade. Miura et al.<sup>(25)</sup> conducted cyclic loading tests on geogrid reinforced subbase and base course aggregates on model flexible pavements. The tests used a soft clay subgrade, an 8-in. subbase, 6-in. base, and 2-in. asphaltic concrete surface. Three types of geogrid (Tensar SS1, SS2, SS3) were tested. A cyclic load of 28 psi and a frequency of 0.18 Hz (4 sec loading and 2 sec unloading) were applied through an 8-in.-diam steel plate. Failure criteria were set at 0.2-in. settlement of the asphaltic concrete surface. Results showed that the number of cyclic loadings increased from 2,500 nonreinforced to 7,500 for SS3 on top of the subgrade, to 10,500 for SS2 on top of the subgrade, and 20,000 for SS2 on top of the subbase. SS1 reinforcement was tested in two layers (on top of the subgrade and the subbase, and on top of the subbase and in the base). The SS1 reinforcement was most effective when placed on top of the subgrade and the subbase. Two layers of SS1 increased the number of cyclic

loadings by a factor of 6. The test results showed that the SS2 reinforcement was more effective than the others.

Based on the model laboratory test program, full-scale test sections were constructed on a public road in Japan. The clay subgrade CBR was 4 to 6. The test sections had an 8-in. subbase, 6-in. base course, and 2-in. asphaltic concrete surfacing. Four geogrid reinforcement test sections were constructed. One test section had SS2 placed on the subgrade, one had SS2 on the subbase, one had SS3 on the subgrade, and one had SS3 on the subbase. No details of traffic type or volumes were given in the report. After 6 months, the road tests indicated that the test section with SS2 geogrid on the subbase performed better than the rest of the geogrid sections.

c. Limited Full-Scale Test on Geogrid Reinforced Heavy-Load Flexible Pavement. Barker<sup>(1)</sup> conducted limited full-scale tests using Tensar SS2 geogrid to reinforce a 6-in. open graded base layer in a heavy-load flexible pavement. The geogrid was placed in the middle of the base layer. Test traffic used a single tire loaded to 27,000 lb and inflated to 265 psi tire pressure (simulating an F-4 aircraft). At the end of traffic tests (1,000 coverages), the surface deformation of the Tensar SS2 item was 2.7 in. compared to a deformation of 3.4 in. in an identical but nonreinforced test item. The SS2 geogrid material was removed and examined after traffic and was found to be in good condition. No other specific conclusions were reported regarding the SS2 geogrid used in these tests.

d. Large-Scale Laboratory and Analytical Studies of Geosynthetic Reinforcement in Flexible Pavements. The most comprehensive work to date on geogrid reinforcement for base courses for flexible pavements was conducted by Barksdale, Brown, and Chan<sup>(2,10)</sup>. The laboratory research was conducted at the University of Nottingham, and the analytical studies were carried out at the Georgia Institute of Technology.

Variables investigated in the laboratory study included the following:

- (1) Type and Stiffness of Reinforcement (Geogrids and High Modulus Woven Geotextiles).
- (2) Reinforcement Position.
- (3) Pavement Strength.
- (4) Geosynthetic Prestressing.
- (5) Prerutting of the Aggregate Base (prerutting is a method of removing slack in the geogrid by rutting and then smoothing the top of the aggregate base before the asphalt surfacing is applied).

The laboratory tests consisted of a 1.0- to 1.5-in.-thick asphalt surfacing placed over a 6- or 8-in.-thick aggregate base. The silty clay subgrade

had a CBR of 2.5. A 1,500-lb moving wheel load was employed in the experiments.

The laboratory and analytical results indicated that geosynthetic reinforcement of an aggregate base can, under the proper conditions, improve pavement performance with respect to both permanent deformation and fatigue. Specific conclusions from the study are as follows:

(1) Type and Stiffness of Geosynthetic. A geogrid having an open mesh has the reinforcing capability of a woven geotextile having a stiffness approximately 2.5 times as great as the geogrid. A geogrid performs differently than a geotextile. Test results indicate that the minimum stiffness to be used for aggregate reinforcement applications should be 1,500 lb/in. for geogrids and 4,000 lb/in. for woven geotextiles.

(2) Geosynthetic Position. For light pavement sections constructed with low-quality aggregate bases, the preferred position for the reinforcement should be in the middle of the base, particularly if a good subgrade is present. For pavements constructed on soft subgrades, the reinforcement should be at or near the bottom of the base. The reinforcement should be at the bottom of the base to be most effective in minimizing permanent deformations in the subgrade.

(3) Improvement Levels. Light sections on weak subgrades reinforced with geosynthetics can give reductions in base thickness of 10 to 20 percent. For weak subgrades and/or low-quality bases, total rutting in the base and subgrade may be reduced by 20 to 40 percent.

(4) Fatigue. The analytical results indicated that improvements in permanent base and subgrade deformations may be greater than the improvement in fatigue life.

(5) Prerutting and Prestressing. Both prerutting the aggregate base and prestressing the geosynthetic can significantly reduce permanent deformations within the base and subgrade. However, stress relaxation with time could significantly reduce the effectiveness of prestressing the geosynthetic in the aggregate.

The authors<sup>(2)</sup> recommended additional research be conducted consisting of carefully instrumented, full-scale field test sections. Geogrid reinforcement is recommended as the primary reinforcement since it was found to perform better than a much stiffer woven geotextile.

e. Design Guidelines for Geogrid Reinforced Base Courses for Flexible Pavements. Almost all research investigating geogrid reinforced pavements used Tensar geogrids. The Tensar Corporation<sup>(31,32,33)</sup> has published design guidelines for flexible pavements with Tensar geogrid reinforced bases. Tensar states that any conventional flexible pavement design procedure can be used to design base layers reinforced with Tensar geogrids by incorporating simple empirical factors that quantify grid performance. If the reinforced base layer thickness is 10 in. or less, the optimum location for the geogrid is at the bottom of the base layer. If the reinforced base layer exceeds

10 in., the geogrid should be placed at or just below the midpoint of the base layer. An equivalency chart for reinforced versus nonreinforced base thickness is provided.

## CONCLUSIONS

### BALLAST REINFORCEMENT FOR RAILROAD TRACK BED

a. Geogrids perform one or more of the following functions when placed in a railroad track: provide lateral and vertical restraint to confine the ballast and resist decompaction, separate dissimilar materials, provide a working platform over very soft subgrade soils, and provide a membrane support by going into tension at relatively low strain levels.

b. Based on current knowledge from laboratory tests and field experience, geogrid reinforcement should not be used to reduce the ballast/subballast thickness required to support railroad wheel loadings, as determined from conventional design procedures.

### REINFORCEMENT FOR AGGREGATE SURFACED PAVEMENTS

a. Both plate-load laboratory and full-scale traffic tests have shown geogrid reinforcement benefits in aggregate surfaced pavements.

b. Laboratory plate failure loads for geogrid reinforced aggregate layers are approximately 40 percent higher than for nonreinforced systems.

c. The improvement mechanisms for geogrid-reinforced aggregate surfaced pavements are as follows:

(1) Subgrade Confinement. If the subgrade soil is confined by the continuity of a reinforcing element (geotextile or geogrid), deformations resulting from local shear failure do not become large and the subgrade soil can support a vertical stress close to its ultimate bearing capacity.

(2) Grid Interlock with Aggregate Base Material. By interlocking with the base layer aggregate, geogrids reduce permanent lateral displacements which accumulate with traffic passes.

(3) Separation. Separation of the base layer and subgrade prevents aggregate contamination and aggregate sinking. Separation reduces degradation of the mechanical properties of the aggregate and helps maintain the thickness of the base layer. Geotextiles are better separators than geogrids. Geotextiles should be used under geogrid reinforcement on low strength (< CBR 1.5) cohesive subgrades.

(4) Tensioned Membrane Effect. Tensioned membrane effect results when the geogrid is stretched due to traffic load rutting. Tensioned membrane effect results in confinement of the subgrade and a reduction of the stress applied by the wheel on the subgrade. Significant rutting is required in order to benefit from tensioned membrane effect.

d. Geogrid base reinforcement benefits are dependent upon the placement depth of the geogrid. Optimum placement depth is probably in the range between 0.3 and 0.6 times the load width.

e. Geogrids perform better than geotextiles in base layer reinforcement mainly because grid interlock with aggregate particles. Poor friction properties of geotextiles do not allow good interlock with aggregate particles.

f. For subgrade CBR strengths of 1.5 to 5.0, geogrid reinforced aggregate surfaced pavements can carry about 3.5 times more traffic than equivalent nonreinforced pavements.

#### REINFORCEMENT FOR FLEXIBLE PAVEMENTS

a. Results of laboratory tests and analytical studies indicate that geogrid reinforcement of aggregate bases can improve pavement performance with respect to both permanent deformation and fatigue.

b. Laboratory plate-load tests indicated that flexible pavements with geogrid reinforced base courses can carry up to three times the number of load applications compared to nonreinforced pavements (based on single layer of reinforcement material and 0.8 in. of permanent deformation in the pavement surface).

c. Laboratory plate-load and moving wheel-load tests, under certain conditions, indicated that geogrid base reinforcement could allow base course thickness reductions ranging from 10 to 50 percent. Weak subgrades and/or low quality bases offer the highest improvement level for geogrid base reinforcement.

d. Almost all geogrid tests conducted to date have been with Tensar SS1, SS2, or SS3 geogrids. The SS2 material has performed the best as base reinforcement for flexible pavements.

e. A geogrid performs differently than a geotextile when used in base reinforcement. A geogrid has the reinforcing capability of a woven geotextile having a 5 percent secant modulus approximately 2.5 times as great as the geogrid.

f. If a subbase is used in a flexible pavement, the geogrid reinforcement should be placed between the base and subbase.

g. Full-scale field traffic tests are needed in order to validate geogrid reinforcement performance and provide data needed for developing design criteria.

h. Important criteria when considering geogrids for base reinforcement include geogrid geometry, mechanical properties, endurance properties, environmental properties, soil/geogrid/aggregate interaction, and geogrid placement location.

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## APPENDIX A: GEOGRID TEST SECTION DESIGN

### PROBLEM

Based on the literature review, geogrids have application in railroad track reinforcement and in reinforcement for aggregate surfaced pavements. Full-scale field tests have verified that for subgrade CBR strengths of 1.5 to 5.0, geogrid reinforced aggregate surfaced pavements can carry about 3.5 times more traffic repetitions than equivalent nonreinforced pavements. The improvement mechanisms for geogrid-reinforced aggregate layers are known and both laboratory and analytical studies indicate that geogrid reinforcement of aggregate bases can improve flexible pavement performance with respect to both permanent deformation and fatigue. The purpose of this field test section effort is to validate the laboratory tests through full-scale traffic tests on flexible pavement test sections for light aircraft. If geogrid base reinforcement can reduce base thickness requirements and the cost of airport pavements, then results of the field tests can be used to develop criteria for incorporating geogrids into FAA pavement design.

### SCOPE

The scope of this effort is limited to base courses for flexible pavements intended to support operations of light aircraft. Chapter 5 of FAA Advisory Circular AC 150/5320-6C contains current design criteria for pavements which serve aircraft of 30,000 lb gross weight or less. Test section design considerations were as follows:

a. Pavement Thickness. The FAA design curves for flexible pavements for light aircraft (Figure A1) show thickness requirements ranging from 5 to 23 in. and CBR strengths from 3.5 to 23. Since geogrid performance is related to its position in a pavement, the field test section design is limited to pavement thicknesses between 5 and 23 in. Also, since this effort is for base reinforcement, no subbase test items were included.

b. Subgrade. Two subgrade strengths were included. A 3 CBR subgrade represents a low strength subgrade which should show good base reinforcement potential without the necessity of a geotextile separator. An 8 CBR subgrade represents a firmer subgrade which will determine if geogrid reinforcement benefits diminish as subgrade strength increases. A CH clay subgrade soil was selected because it can be processed to selected moisture contents and compacted in layers to design CBR strength that will not change significantly throughout traffic testing.

c. Geogrid Reinforcement. Since almost all geogrid tests conducted to date have used Tensar SS1, SS2, or SS3 geogrids and the SS2 geogrid has performed the best, the SS2 was selected as the main reinforcement in the test section design. Since the physical and mechanical properties of the various geogrid products available on the market vary substantially, a portion of the field tests was devoted to comparative performance testing of the product types available. These performance results will be required for preparing generic specifications on the use of geogrids. Based on the literature review, a laboratory test program, by itself, for geogrid performance

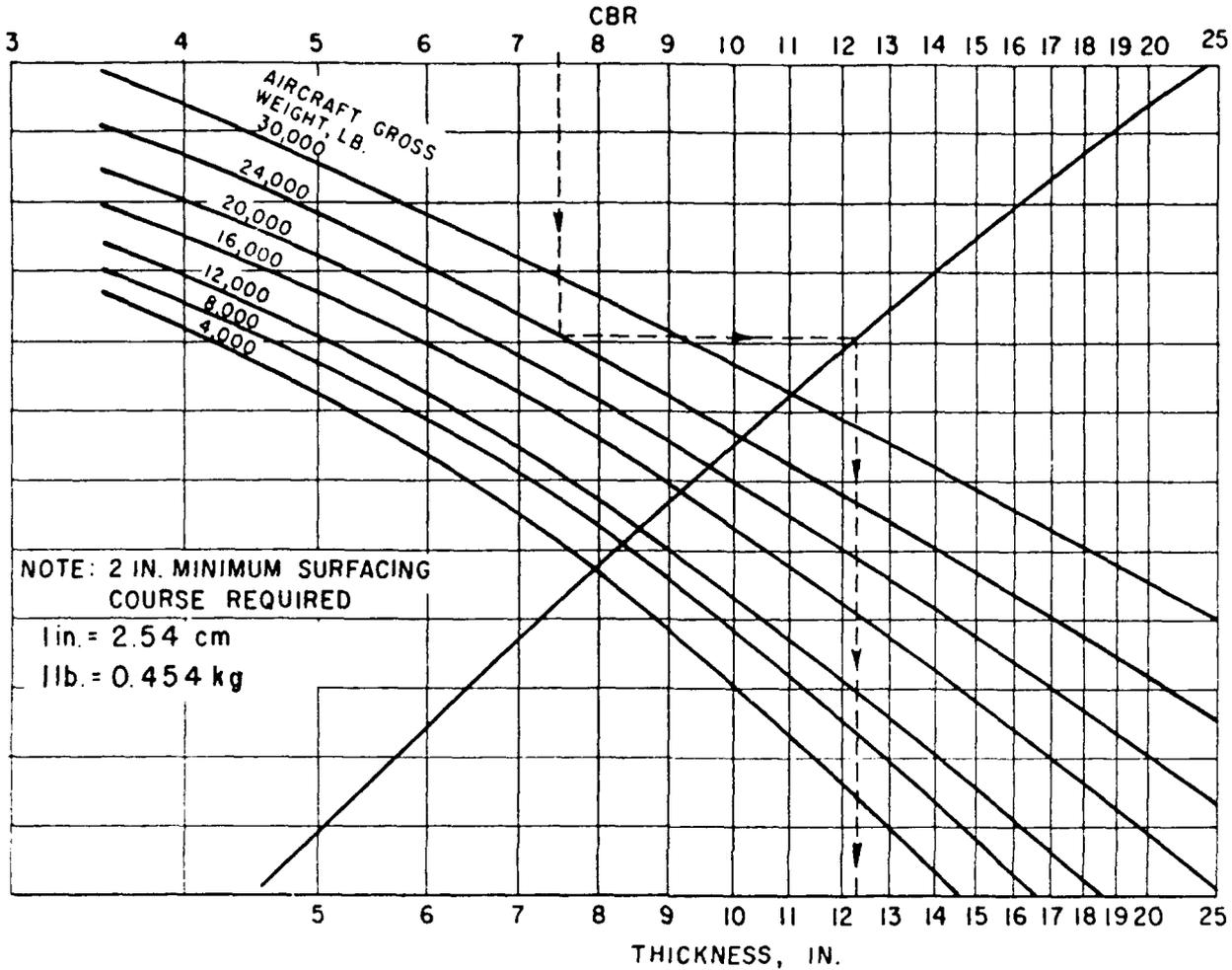


Figure A1. Design curves for flexible pavements, light aircraft

equivalency would be unreliable. Laboratory tests will be utilized to support the field results.

d. Traffic Test Load. A 30,000 lb single tire load with a 68 psi tire contact pressure was selected for use in the traffic tests. This tire load/pressure combination will allow accelerated testing of the various test section items. The tire contact width for this load configuration is 17.5 in.

#### TEST SECTION DESIGN

A layout of the test section is shown in Figure A2. The test section contains four traffic lanes. Each traffic lane contains four test items. Traffic Lanes 1 and 2 will utilize distributed type traffic (see Figure A3) over a width of five wheel widths. A three-factor experimental design model for traffic Lanes 1 and 2 is shown in Figure A4. Test items within these lanes were designed to measure the base reinforcement potential of geogrids. Traffic Lanes 3 and 4 will utilize channelized traffic and were designed to determine economically the comparative performance of the various types of

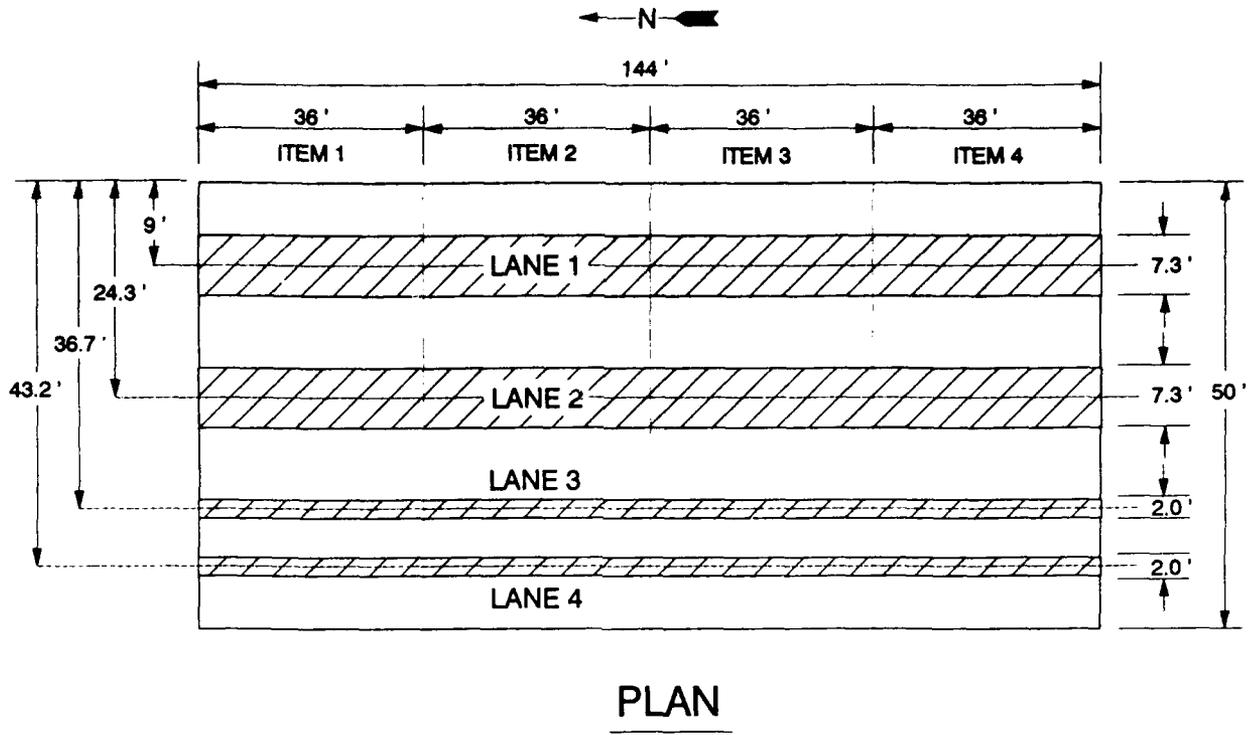
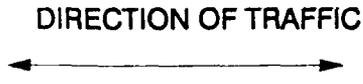


Figure A2. Layout of geogrid test section



WHEEL PATH NUMBER	WHEEL PASS NUMBER	COVERAGES
1	1	1
2	2, 8	2
3	3, 7, 9	3
4	4, 6	2
5	5	1

Figure A3. Traffic pattern for test Lanes 1 and 2

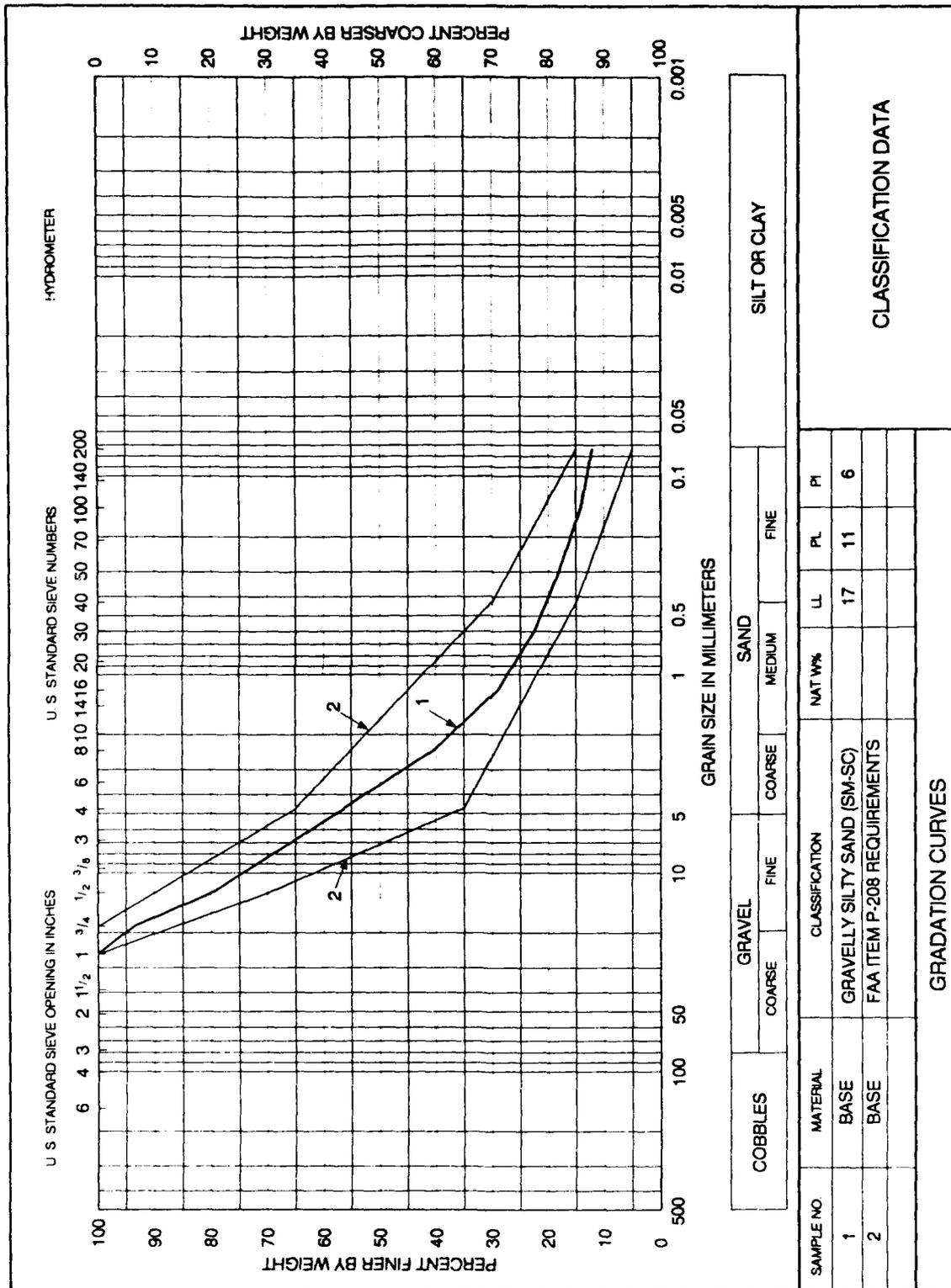
GEOGRID REINFORCEMENT		NO REINFORCEMENT		SS-2 GEOGRID	
		THICK	THIN	THICK	THIN
BASE COURSE	8 CBR	Lane 1 Item 1  2" AC 10" Base	Lane 1 Item 4  2" AC 6" Base	Lane 1 Item 2  2" AC 10" Base SS-2	Lane 1 Item 3  2" AC 6" Base SS-2
	3 CBR	Lane 2 Item 1  2" AC 18" Base	Lane 2 Item 4  2" AC 12" Base	Lane 2 Item 2  2" AC 18" Base SS-2	Lane 2 Item 3  2" AC 12" Base SS-2
SUBGRADE STRENGTH					

Figure A4. Experimental design for traffic Lanes 1 and 2

geogird products available on the market. All test items have a 2-in. asphaltic concrete surface meeting FAA Item P-401 requirements. A marginal-graded crushed limestone was selected as base course material. This material (Figure A5) marginally meets the FAA Item P-208 for aggregate base course. The material is marginal because the amount of the fraction of material passing the No. 200 mesh (12.3 percent) exceeds the limit of one-half the fraction passing the No. 40 mesh (22.0 percent). Results from the literature review indicated that lower quality bases offered the highest improvement level for geogrid base reinforcement.

a. Traffic Lane 1. Figure A6 shows a profile section of traffic Lane 1. This lane contains two base course thicknesses, each with and without SS2 geogrid reinforcement placed at the bottom of the base. The conventional nonreinforced test Item 4 was designed to fail (1-in. rut) at a low coverage level (less than 100 coverages). Item 1 was designed to fail at less than 500 coverages of test traffic. Items 2 and 3 were designed to measure direct performance improvement using geogrid reinforcement.

b. Traffic Lane 2. Figure A7 shows the profile of Lane 2. The base layer thicknesses of this lane were designed to fail at approximately the same coverage levels as those in Lane 1. The 3 CBR subgrade should allow good



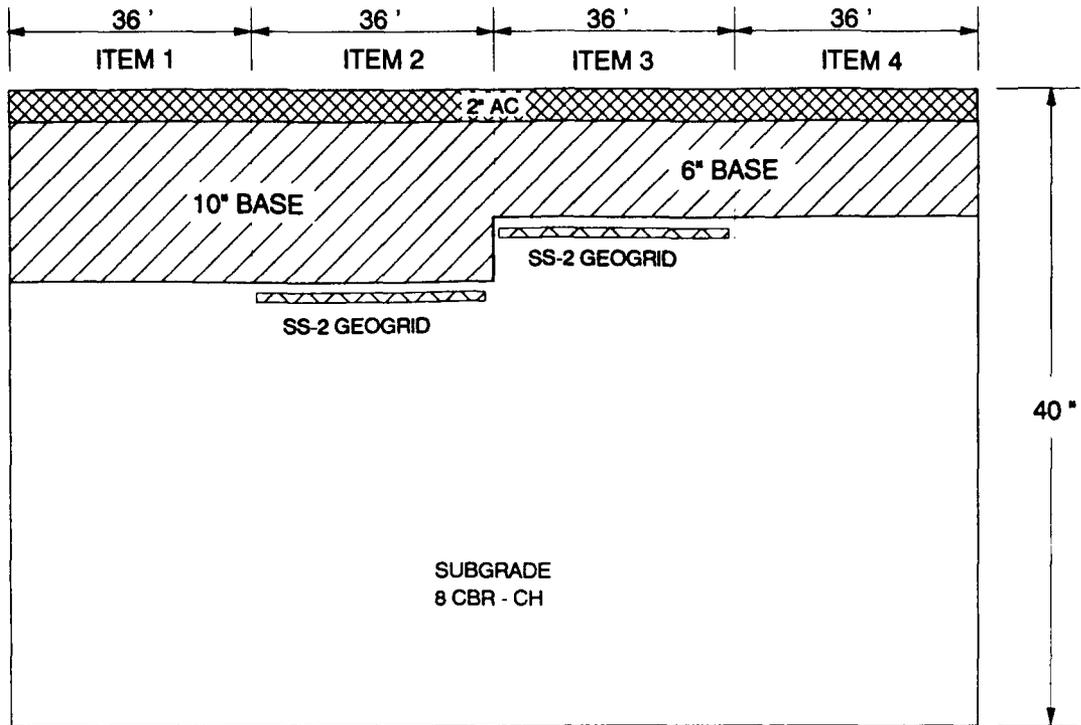


Figure A6. Profile of traffic Lane 1

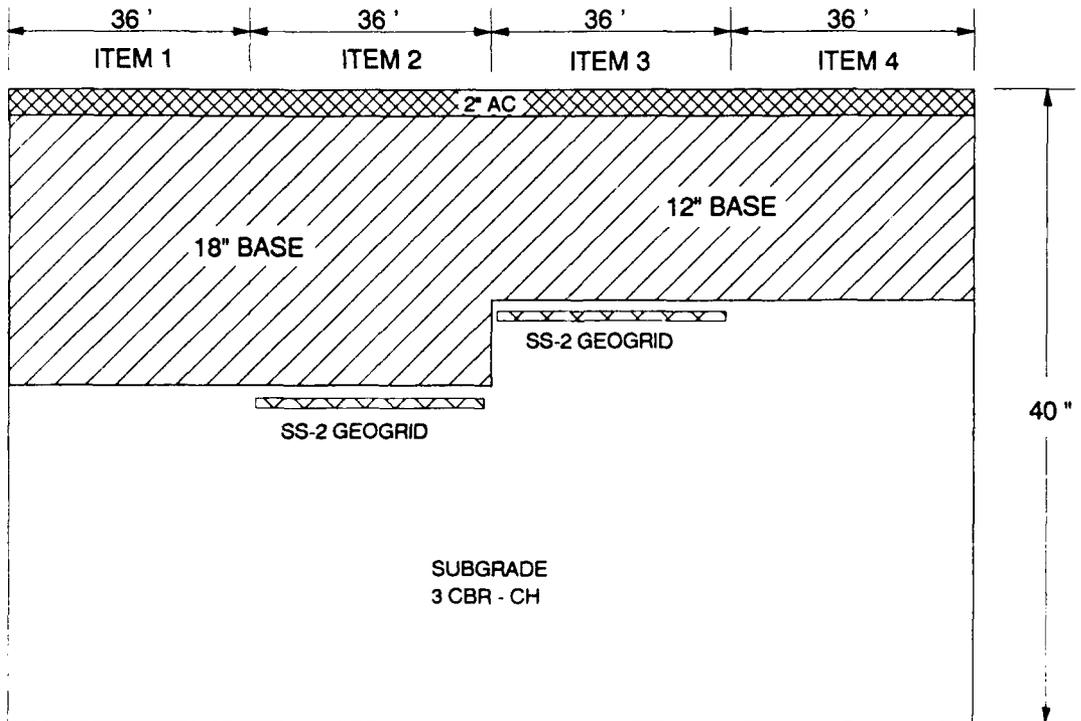


Figure A7. Profile of traffic Lane 2

reinforcement potential for geogrids and also test the geogrid performance at a relatively deep (20-in. depth) location in the pavement.

c. Traffic Lanes 3 and 4. Figures A8 and A9 show the profiles of Lanes 3 and 4, respectively. These two traffic lanes were designed to accomplish the following.

(1) Lane 3 (Items 2 and 3) will test the most effective location for the geogrid. On relatively thick pavements, laboratory tests have shown better performance with the geogrid placed in the middle of the base layer.

(2) Lane 3 (Items 3 and 4) will test the importance of the geogrid secant modulus for the same type material (SS-2 versus SS-1).

(3) Lane 3 (Items 1 and 2) and Lane 4 (Items 1 to 3) will test the comparative performance of the various types of geogrid products available on the market. The performance variables of these products include structure, polymer composition, junction method, mass per unit area, aperture size, thickness, and tensile strengths. No known laboratory test program could be substituted and accomplish what these tests items will provide.

(4) Lane 4 (Item 4) will serve as a control item to compare with the reinforcement items in the channelized traffic Lanes 3 and 4.

#### TEST DATA COLLECTION

The primary indicators of pavement performance for the various test items will be rutting and fatigue cracking. Failure criteria for traffic Lanes 1 and 2 will be a 1-in. rut depth or surface cracking to the point that the pavement is no longer waterproof. For comparative purposes, data collection on traffic lanes 3 and 4 will be continued until approximately 3 in. of rutting occurs. In addition to periodic condition surveys to measure and observe rutting and cracking conditions, the following test data will be collected.

a. Cross section level readings will be made at periodic traffic levels on the pavement surface. At the conclusion of traffic, test trenches will be dug and cross-section level readings will be made on top of the geogrid surface.

b. Falling weight deflectometer data will be obtained at periodic traffic levels.

c. Multi-depth deflectometer measuring devices will be installed in test items 1 and 2 of traffic Lanes 1 and 2 to measure deflections under traffic loads at various depths within the pavement layers.

d. Moisture and density tests will be used on the base and subgrade materials.

e. California Bearing Ratio (CBR) tests will be used on the base and subgrade materials.

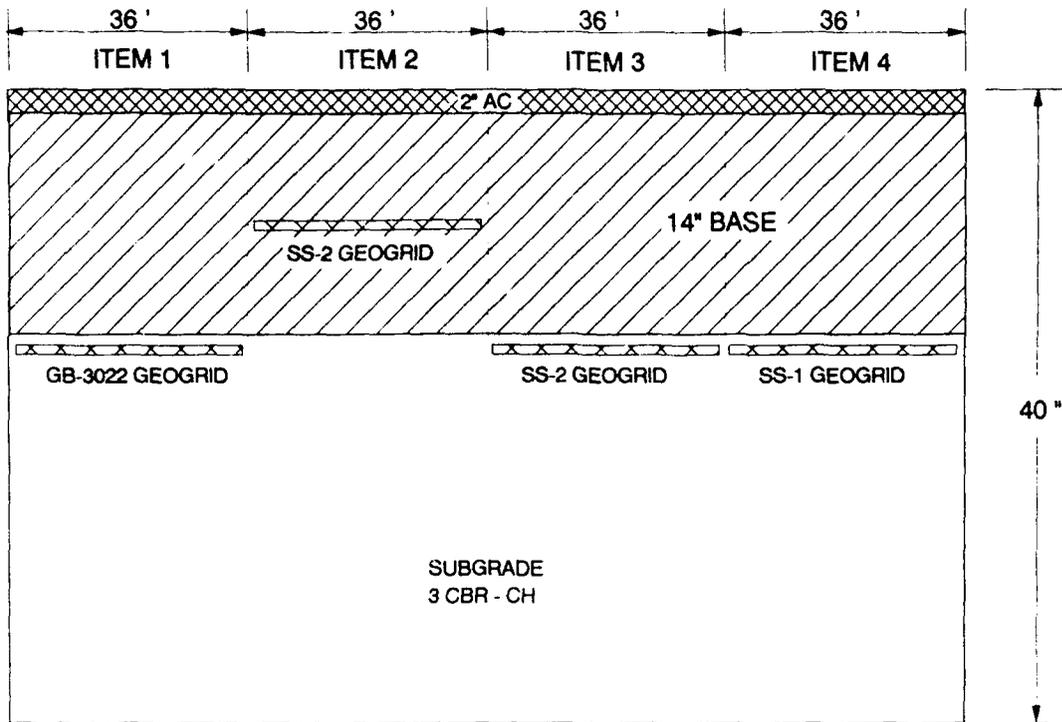


Figure A8. Profile of traffic Lane 3

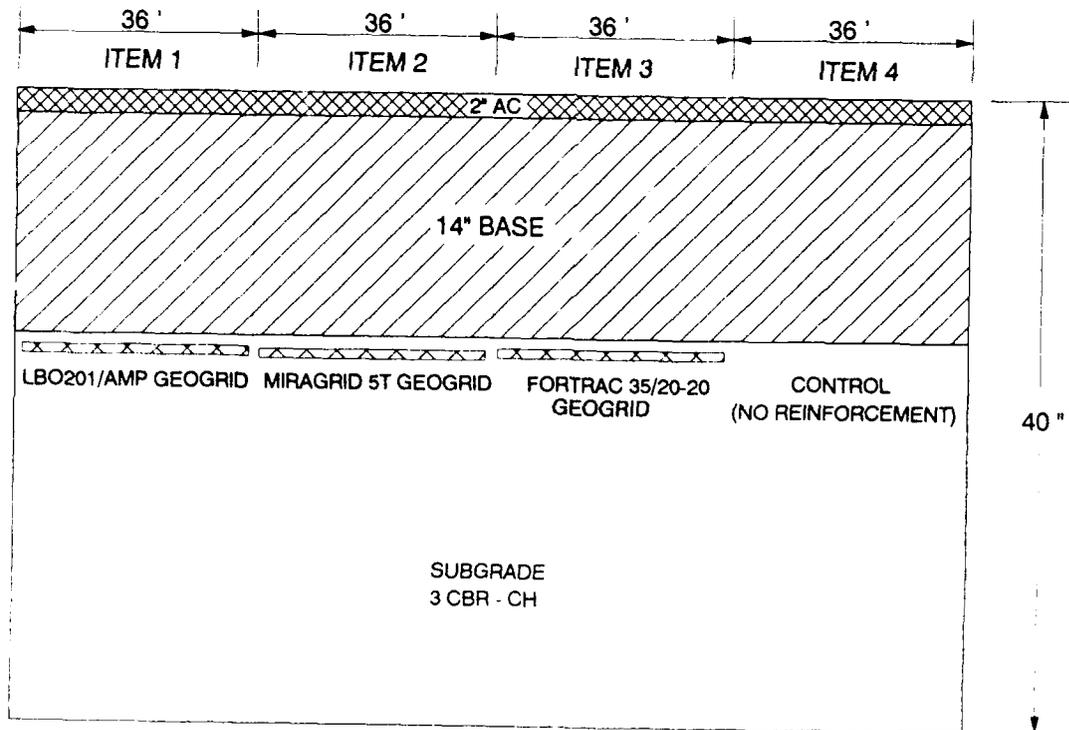


Figure A9. Profile of traffic Lane 4

f. Dynamic Cone Penetrometer (DCP) profile strength tests will be used in the base and subgrade materials.

g. At the conclusion of traffic testing, samples of the geogrid materials will be removed from the test items for observation and laboratory testing.