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USE OF GEOGRIDS IN RAILROAD TRACK: A LITERATURE REVIEW AND SYNOPSIS

by

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All available technical literature applicable to the use of geogrids in railroad track was reviewed during this study. In addition, a number of telephone calls and personal contacts were made with people in academia and in the geosynthetics and railroad industries who have been involved with the development, testing, and use of these materials in railroad track.

A synopsis of the information that is currently available in relation to the use of geogrids in railroad track reinforcement is presented along with recommendations for the use of geogrids on low traffic density, low speed railroad tracks typical of those found on military installations.

PREFACE

The study reported herein was conducted and the report was prepared for the US Army Engineer District, Omaha, under Military Interdepartmental Purchase Request (MIPR) No. ENS 9569 dated 22 September 1989.

This study was conducted by the Pavement Systems Division (PSD), Geotechnical Laboratory (GL), of the US Army Engineer Waterways Experiment Station (WES) from 1 October through 30 November 1989. Personnel of the PSD involved in this study were Messrs. G. L. Carr and D. M. Coleman. The report was written by Mr. Coleman.

This work was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, and under the direct supervision of Mr. H. H. Ulery, Jr., Chief, PSD, and Dr. A. J. Bush III, Chief, Criteria Development and Applications Branch, PSD. This report was edited by Ms. Odell F. Allen, Visual Production Center, Information Technology Laboratory.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
ounces (mass) per square yard	33.90575	grams per square metre
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimetres

USE OF GEOGRIDS IN RAILROAD TRACK:
A LITERATURE REVIEW AND SYNOPSIS

PART I: INTRODUCTION

Background

1. The use of geosynthetics to improve or modify the behavior of soil, aggregate, and other construction materials has increased dramatically in the last decade. Geosynthetics is a generic term for all synthetic materials used in geotechnical engineering applications including geotextiles, geogrids, geomembranes, geocells, and geocomposites. In Designing With Geosynthetics, Koerner (1986) defines these products as follows:

- a. Geotextile. Any permeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related materials as an integral part of a human-made project, structure, or system.
- b. Geogrid. A deformed or nondeformed net-like polymeric material used with foundation, soil, rock, earth, or any other geotechnical engineering-related materials as an integral part of a human-made project, structure, or system.
- c. Geomembrane. An essentially impermeable membrane used with foundation, soil, rock, earth, or any other geotechnical engineering-related materials as an integral part of a human-made project, structure, or system.
- d. Geocell. A three-dimensional structure filled with soil, thereby forming a mattress for increased bearing capacity and maneuverability on loose or compressible subsoils.
- e. Geocomposite. A manufactured material using geotextiles, geogrids, and/or geomembranes in laminated or composite form.

2. The rapid acceptance of geosynthetics in civil engineering has resulted in a large volume of literature on various aspects of their manufacture, testing, and application. While the applications of geosynthetics are numerous and varied, there are several common functions for which the major types of geosynthetics are used. Table 1 summarizes these uses and indicates the primary and secondary functions of the various products.

3. As indicated in Table 1, the primary function of a geogrid is reinforcement, and the secondary function is separation. However, the ability of a geogrid to act as a separator is dependent upon the size of the adjacent

Table 1
Common Functions of Major Types of Geosynthetics

<u>Function</u>	<u>Products</u>			
	<u>Geotextile</u>	<u>Geomembrane</u>	<u>Geogrid</u>	<u>Geocomposite/net</u>
Separation	P*	P	S	S
Filtration	P			S
Drainage/Transmission	P			P
Reinforcement	S		P	
Isolation (water/ vapor barrier)		P		

* P = Primary function; S = Secondary function.

materials. Some of the uses of geogrids that have been reported in the literature include installations in asphalt pavement; pavement base courses; railroad ballast; fills and earth dams; temporary roads and construction sites; repairs of slope failures and landslides; gabions for walls, abutments, and erosion control structures; and earth anchors for retaining walls.

4. The US Army Engineer District, Omaha (CEMRO-ED), is responsible for the design and construction of railroad track at a number of Army and Air Force installations. The question has been raised as to the benefit of including a geogrid in the railroad ballast to act as a reinforcement mechanism. There are different viewpoints and opinions as to the benefit of using a geogrid in a railroad track. In addition, the technical literature and practical experience in this area are relatively limited. Due to the varying opinions and lack of readily available technical information, CEMRO requested the US Army Engineer Waterways Experiment Station (WES) to conduct a literature review and make recommendations on the use of geogrids in railroad track.

Purpose

5. The purpose of this study and report is to investigate the use of geogrids in railroad track applications and to determine if the thickness of ballast can be reduced by the use of these geogrids.

Scope

6. The scope of this investigation included the application of geogrids as a reinforcement in a conventional railroad track structure. Included in this investigation were the advantages and disadvantages of using geogrids and the possibility of reducing the ballast thickness through the use of a geogrid. While there is a significant amount of literature devoted to testing geogrids and the mechanical properties of the materials, these areas were not investigated as they are outside the scope of this study. Likewise, the use of geogrids in slope reinforcement, retaining wall, temporary construction, gabions, and erosion control applications is not within the scope of this project and was not investigated.

7. During this study 32 different books, reports, technical papers, and magazine articles were reviewed. A complete bibliography of these publications is provided in Appendix A. These references were obtained after extensive information searches using the WES library and four computer data bases. The data bases searched were the Transportation Research Information Service, Engineering Index (COMPENDEX PLUS), National Technical Information Service, and Conference Paper Index.

8. Of these 32 publications, only 12 were directly related to the use of geogrids in railroad ballast. Thirteen publications discussed the use of geogrids in reinforcing asphaltic concrete pavement, granular bases in pavements, and granular layers over very soft subgrades. These publications were included even though they are not directly related to railroads because much of the theoretical and laboratory testing of geogrids has been directed at pavement applications. Five publications covered various aspects of geogrid-soil interaction and model tests of geogrid reinforced systems. Of the 32 publications, 6 of them were manufacturer's literature covering both granular base reinforcement and railroad applications.

9. In addition to reviewing published literature, a number of telephone calls were made to people in the railroad and geosynthetic industries and in academia who have been involved with the development, research, and use of geogrids in railroad track. A complete listing of these personal conversations is provided in Appendix B.

PART II: RAILROAD TRACK STRUCTURE

General

10. The conventional railroad track is a structure constructed to provide guidance for locomotive and rolling stock wheels, support the loads resulting from these wheels, and distribute the wheel/axle loads throughout the track structure in such a manner that the individual components of the structure are not overstressed. The conventional railroad track structure is composed of rails, tie plates, ties, associated fastening (joint bars, spikes, etc.), ballast, subballast, and the subgrade.

11. The distribution of the load from the wheel to the subgrade is one of the most important functions of the track structure. A 30,000-lb* wheel load acting on an approximately 1/2-sq-in. contact area creates a contact stress on the rail of 60,000 psi. Most reasonably firm subgrades will support vertical stresses in the range of 10 to 20 psi without severe deformation. The track structure must reduce the wheel load stress that acts on the rail to a stress that the subgrade will support. If the subgrade will not support the stresses transmitted through the track structure, loss of surface (crosslevel, profile), alignment, and gage will occur along with pumping, ballast fouling, and general subgrade subsidence.

Ballast and Subballast

12. Ballast is a select, granular material placed on the subgrade to restrain the track laterally, longitudinally, and vertically under the dynamic loads imposed by trains and the thermal stresses induced in the rails by changing temperatures; provide adequate drainage of the track; transmit and uniformly distribute the load of the track and trains to the subgrade in a manner that prevents overstressing of the subgrade; and facilitate track maintenance. Some of the characteristics of good ballast are strength, toughness,

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3. Non-SI units are used throughout this report except where SI units were used on the original measurements and are repeated herein. Then the SI units are given with the approximate non-SI equivalent provided in parentheses for the convenience of the reader.

durability, stability, drainability, cleanability, resistance to deformation, and overall economy. Commonly used ballast materials include crushed stone and crushed slag with the gradations ranging from 3-1/2 to 3/4 in.

13. Subballast is a lesser quality ballast-type material that is placed under the ballast but above the subgrade. The primary functions of the subballast are to distribute the vertical ballast pressures to the subgrade, act as a filter layer to prevent ballast fouling, and help protect the subgrade from frost penetration. Granular materials such as crushed stone, crushed slag, soil-aggregate mixtures, and stabilized materials are often used as subballast.

14. The thickness of the ballast and subballast will vary depending on the subgrade strength and the magnitude of the wheel loads and traffic volumes. Typical thicknesses for track over reasonably firm subgrades are 8 to 12 in. of ballast combined with 6 to 12 in. of subballast. Recently revised Army/Air Force Criteria (Headquarters, Department of Army and Air Force 1990) require a minimum ballast/subballast thickness of 12 in. with a minimum of 6 in. of ballast and 6 in. of subballast. Note that these are minimum thicknesses, and greater depths may be required depending on the subgrade type/strength, traffic volumes, and wheel loads. The actual ballast/subballast thickness requirements must be determined as a part of the track design.

PART III: INTRODUCTION TO GEOGRIDS

15. One definition of geogrid has been given in the background section of this report. However, a more precise definition for geogrid is given by Carroll (1988) as "... any synthetic planar structure formed by a regular network of tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock, earth, or any other geotechnical material to perform the functions of reinforcement and/or segregation." The openings in the geogrid are designed to provide a means of interlocking with soil or granular materials. Geogrids are also designed to provide high tensile modulus or high reinforcing strength at very low elongations. This modulus is generally referenced as the secant modulus measured at 2 percent strain. Figure 1 shows a typical example of biaxial geogrids that would be used for ballast reinforcement in railroad track.

16. The basic material used for manufacturing geogrids is either polypropylene or high-density polyethylene. To manufacture geogrids, holes are punched in a large sheet of the parent material to form a regular pattern. The sheet is then drawn either uniaxially or biaxially under controlled

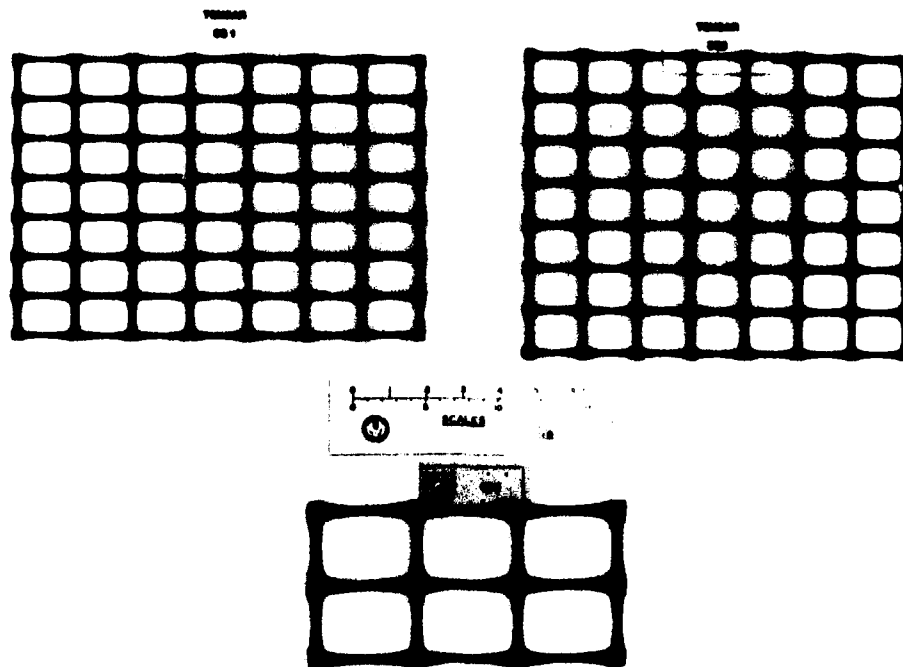


Figure 1. Biaxial geogrids typically used for railroad applications

temperatures and strain rates. This drawing increases the modulus and strength of the material and reduces the creep sensitivity of the material. The uniaxial grids provide reinforcement strength primarily in one direction (along the length of the material) while the biaxial grids provide reinforcement both across the width and along the length of the material. In addition to the planar materials, a welded grid is also available. These welded grids are produced from highly oriented components which are welded into the finished grid. Regardless of the type of manufacture, the basic functions, applications, advantages, and limitations of geogrids are the same.

17. Because of the requirement for bidirectional reinforcement, a biaxial grid is generally recommended for in-track applications. Considerations in specifying geogrids for in-track applications include the grid's aperture size, percent open area, rib thickness, tensile modulus, junction strength, and flexural rigidity. A Geotechnical Fabrics Report article entitled "Specifying Geogrids" (Carroll 1988) provides a good, general overview on the process of specifying geogrids. It should be noted that there have been few applications of geogrids in a railroad track structure where the long-term performance of the section has been monitored and the results documented. Therefore, there is really no field-proven guidance on the physical properties of the geogrids (e.g. tensile modulus) that are required for successful railroad track applications.

PART IV: SYNOPSIS OF LITERATURE

Railroad Track Reinforcement

18. Almost all of the laboratory testing and research on geogrids for railroad track applications have been performed by the Royal Military College of Canada and Queens University at Kingston, Ontario, Canada. This work has been reported in papers presented at and published in the proceedings of the Third International Conference on Geotextiles (Bathurst, Raymond, and Jarrett 1986) and the Transportation Research Board (Bathurst and Raymond 1987). The same information is presented in both of these papers. During this research large-scale models of a single tie/granular ballast system were constructed over artificial subballast/subgrade supports of varying strengths and a cyclic load applied. The test configuration consisted of 450 mm (18 in.) of ballast confined in a rigid test box 3 m (9.8 ft) long by 1.5 m (4.9 ft) wide. The subballast/subgrade layers were represented by the concrete floor and by rubber mats of various stiffnesses. The rubber mats simulated subballast/subgrade layers having strengths of 1, 10, and 39 CBR* (California Bearing Ratio), and the concrete floor simulated a completely rigid layer. The ballast was loaded using a steel footing 920 mm (36 in.) long by 250 mm (10 in.) wide by 150 mm (6 in.) deep placed within the top of the ballast layer. This footing approximately models one-half of the bearing area of a typical tie. An 85-kN (19,100-lb) peak load was applied to the footing at selected frequencies to simulate train traffic. Between 36,000 and 1,000,000 load repetitions were applied during each test. This number of load repetitions represents between 0.34 and 10 million gross tons (MGT) of rail traffic. Tests were performed with the ballast section unreinforced and with a biaxial high density polyethylene polymer (square openings of 46 mm) geogrid placed at depths of 50 mm (2 in.), 100 mm (4 in.), 150 mm (6 in.), and 200 mm (8 in.) below the base of the footing. A load cell and displacement transducers were used to monitor the applied load and vertical tie displacements during the tests. At

* CBR is a measure of the resistance of soils to the penetration of a standard 3 sq in.-piston and is determined by comparing the bearing value obtained from a penetration-type shear test with a standard bearing value obtained on crushed rock. The test results are expressed as a percentage of the standard bearing value.

certain intervals the load-deformation response of the footing was measured and recorded.

19. The published results and conclusions from this testing program are summarized as follows:

- a. Geogrid reinforcement decreases the rate of permanent deformation within ballast placed over soft (compressible) subgrades. After 200,000 load repetitions (approximating 1.9 MGT of traffic), there was no performance benefit due to the inclusion of the geogrid reinforcement in ballast over the rigid subgrade sections.
- b. The compressibility of the artificial subballast/subgrade was the greatest influence on the generation of permanent deformations beneath the tie. Increases in permanent deformation were proportional to increases in the subballast/subgrade compressibility for both the unreinforced and reinforced sections.
- c. As the compressibility of the subballast/subgrade increases, the benefit of the geogrid reinforcement increases. For the reinforced ballast over the very flexible (1 CBR) subgrade, the permanent deformation after 100,000 load applications was approximately 50 percent of those recorded for the unreinforced case at that load level.
- d. Test results indicated an optimum placement depth of 50 mm (2 in.) for ballast reinforcement. However, to prevent damage to the geogrid by tamping equipment, a minimum placement depth of 200 mm (8 in.) is recommended.
- e. For compressible subgrades (1 to 39 CBR) having ballast reinforcement placed 150 to 200 mm (6 to 8 in.) below the tie, the number of load repetitions required to reach a 50-mm (2-in.) settlement criterion was projected to be approximately one order of magnitude greater than that for unreinforced sections.

20. Other points were gleaned from the review of these papers, even though these were not presented in the published conclusions. These points were:

- a. Most of the ballast settlement came within the first 1 MGT of load with very little permanent deformation occurring between 1 and 10 MGT.
- b. Upon completion of each test, ballast particles were observed to be wedged in the geogrid openings. This indicates that geogrid-ballast interlock is occurring and is assisting to resist lateral deformation of the ballast under the repeated loading.
- c. Upon excavation of the geogrids from the reinforced ballast sections over the compressible subgrades, large, well-pronounced depression bowls were observed. This is consistent with the widely held belief that large deformations of the surrounding aggregate (ballast) are required to mobilize the tensile/interlocking capacity of the geogrid.

- d. The 50 percent reduction in permanent deformations reported in Paragraph 19 above was the maximum reduction in deformation. Test data indicated reductions in permanent deformations varying from 25 to 50 percent after 100,000 load applications depending on the support conditions and placement depth. The 50 mm (2 in.) placement depth that proved to be the optimum is not practical for real-world application where at least 8 in. is required between the bottom of the tie and the geogrid to protect the geogrid.
- e. A combination of criteria must be met before the use of ballast reinforcement can be considered a cost-effective means of improving track performance. If the track support is stiff, the performance difference between the unreinforced and reinforced ballast sections is negligible. If the track support is too compressible, the reinforcement benefit is great, but the maintenance cycle (time between surfacings) remains uneconomically short. A modest improvement in the quality of the subballast and/or subgrade may be equally effective in producing the desired benefit. In the case of new construction, subballast/subgrade improvements will likely be more cost effective. However, for rehabilitation of existing track, the reinforced section may be preferred.

21. The same information reported in the two technical papers discussed in Paragraphs 18-20 is repeated in two different publications produced by a geogrid manufacturer. Tensar Technical Note TTN:RR1 entitled Large Scale Testing of Tensar Geogrid Reinforced Railway Ballast (Raymond et al. 1986) presents a summary of the objectives and conclusions from the above referenced reports. Tensar Technical Note TTN:RR2 entitled Geogrid Reinforcement of Ballasted Track (Bathurst and Raymond 1987a) is a reprint of the Transportation Research Board paper (Bathurst and Raymond 1987b) and therefore contains the same information.

22. Although several commercial railroads have used geogrids to reinforce ballast/subballast in problem areas, only one case has been documented in the technical literature. This case involves the use of geogrids and geotextiles in the reconstruction of a section of unstable track owned by CSX Transportation near Milledgeville, AL. This track rehabilitation has been discussed in one technical paper and several general-interest articles. A technical paper entitled "Railroad Ballast Reinforcement Using Geogrids" was published in the Geosynthetics '87 Conference Proceedings (Walls and Galbreath 1987). More general and less detailed information on this particular project is given in "Railroad Track Structure Stabilized With Geosynthetics" (Newby and Walls 1987) and in "Geogrid Proving Itself" from Railway Track and Structures (1987).

23. The case study reported by Walls and Galbreath (1987) describes the repair of a 2,000-m (6,562-ft) section of mainline track in Alabama where weak subgrade soil and a high-ground water table combined to cause repeated track failures and continual maintenance problems. The track conditions were such that track surfacing and alignment were required every 2 to 4 weeks, and a permanent slow order of 5 mph was placed on the track. After several unsuccessful attempts to stabilize the track, the section was successfully repaired using new drainage facilities, a geotextile, and a geogrid for reinforcing the ballast. The function of the geogrid in this project was to preserve the integrity of the ballast by rigidly confining the aggregate thereby restricting the vertical and lateral movement of the ballast.

24. The reconstruction of this section of track was accomplished much like routine track maintenance. The first step in the reconstruction was to raise the track (rail and ties) and remove the fouled ballast using a sled pulled by a backhoe. Once the sledding was completed, the track was raised using power jacks, and the geotextile and geogrid were unrolled simultaneously over the existing subballast. When the geotextile and geogrid were in place, they were pulled tight and the track was lowered onto the grid. New ballast was dumped from railcars and leveled with a tie pulled behind the ballast car. The last step was to raise the track and tamp the ballast using conventional tamping equipment. The cross section of the completed track from below the tie was 12 in. of new ballast, Tensar geogrid, 11 oz/sq yd of geotextile, approximately 10 in. of subballast, and subgrade.

25. Walls and Galbreath (1987) pointed out in their conclusions that the geogrids are an effective and economical method for reinforcing railroad ballast and minimizing or preventing track stability problems. Other conclusions are:

- a. Properly sized geogrids will interlock with and confine the ballast to help resist both lateral and vertical movement of the ballast.
- b. Reinforcement of the ballast with a geogrid is beneficial in reducing the magnitude of the shearing stresses transmitted to the subballast and subgrade, a function that is particularly important when the track is built over low shear strength soils.
- c. Geogrids are most effective when used in conjunction with an appropriate geotextile that will provide adequate separation between the subgrade and the subballast or ballast.

- d. Inclusion of a geogrid in the ballast is possible during routine maintenance activities in which the ballast is replaced or new ballast is added. No difficult or additional steps are required to install the geogrid near the bottom of the new ballast.
- e. Conventional tamping equipment can be used to raise and surface the track and to tamp the ballast without damage to the geogrid, provided that there is at least 8 in. of ballast between the geogrid and the base of the tie before tamping begins.

26. The reconstruction of this track took place in December 1983. Walls and Galbreath (1987) state that within 3 months after reconstruction the 5 mph speed restriction was raised to 35 mph and no track stability problems were encountered. A November 1989 telephone conversation with Mr. A. C. Parker, Assistant Chief Engineer with CSX Transportation, indicated that this section of track was still performing well after almost 6 years of traffic. Mr. Parker said that they had been pleased with the overall performance of the geogrid in this application.*

27. Another recent application of geogrids was their use in the rehabilitation of transit track owned by the New Orleans Transit Authority. A limited amount of information on this project is given in a Contech Construction Products sales brochure entitled New Orleans Transit Authority Reduces Ballast Requirements With Tensar Geogrids (Contech Construction Products, Inc. 1989). In this publication the reconstruction of approximately 14 miles of light transit track is discussed. The existing rail, ties, and ballast were removed. Because of the high water table and soft soils in this area, the old track was built on cypress boards that served as a foundation. The old ballast was removed down to these boards but the boards were not disturbed. A 1-in. sand layer was placed on the boards and the geotextile was placed on top of the sand. Four inches of ballast rock was placed, leveled, and compacted. The geogrid was placed on this first layer of ballast before the track was rebuilt and the remaining 8 in. of ballast was installed.

28. One of the items in the Contech Application Bulletin that appeared promising was the claimed 40 to 65 percent decrease in effective stress due to the installation of the geogrid. It turns out that these figures were arrived at based on theoretical calculations using layered elastic theory and were not

* Personal Communication, November 21, 1989. A. C. Parker, Assistant Chief Engineer, CSX Transportation, Jacksonville, FL.

based on field or laboratory measurements. A layered elastic computer code was used to model both reinforced and nonreinforced granular bases. It is felt by the geogrid manufacturer that the geogrid will increase the Young's Modulus (E) of the granular layer by a factor of 1.5 to 2.0. However, the overall effect of this stiffening and any reductions in vertical pressure will depend upon a number of factors, including the existing subgrade strength. In short, the weaker the subgrade the more the beneficial effect of the geogrid. The 40 percent reduction was based on calculations of one layer of geogrid that was used under the mainline track, and the 65 percent reduction was calculated for two layers of geogrid that reinforced the track under road crossings.*

29. Indications are that the primary purpose for using geogrids in this project was to provide interlock of the ballast particles and some reduction in the vertical stresses that are transmitted to the extremely soft subgrade. Since one of the primary construction problems in the New Orleans area is differential settlements, the geogrid serves to prevent or at least reduce these settlements. This transit project has a long design life, and the geogrid provides an extra measure of protection to help prevent differential settlement of the track over the life of the project. There was no reduction in the ballast thickness even though the geogrid was used. It was felt by the designers that the relatively small cost of the geogrids made their inclusion in the track worthwhile as extra insurance against differential settlement and major maintenance during the life of the project.**

30. Information on only one other project has been published in the technical literature. The paper entitled "Geomembrane-Geotextile-Geogrid Composites in a Railroad Application" was presented at the International Conference on Geomembranes and published in the Proceedings (Fluet and Koehler 1984). The paper describes the design of a railroad project which uses several different geosynthetics. This project involved problems with soft soils, high water tables, limited right-of-way, and radical changes in track stiffness that had to be dealt with in the reconstruction of a section of track. While no details of the actual construction or the end results

* Personal Communication, November 19, 1989. Robert Carroll, Sale Engineer, Tensar Corp., Morrow, GA.

** Personal Communication, November 1989. John L. Montz, Project Manager, Daniel, Mann, Johnson, Mendenhall, Inc., New Orleans, LA.

achieved are given, this article does provide some information on the design process of using geogrids to help solve special problems.

31. Several other general articles describing the use of geogrids were found in various magazines. However, these articles were very general in nature and where specific data were cited, they referred to the cases discussed previously. These articles are listed in the Bibliography given in Appendix A.

Reinforcement for Aggregate Surfaced and Flexible Pavements

32. The available literature concerning the use of geogrids as reinforcement for aggregate surfaced roads, granular bases, and asphalt pavement reinforcement amounted to 12 publications. These can be divided into three general groups that cover laboratory tests of geogrids in unsurfaced granular bases and in flexible pavements, field tests of geogrids in unsurfaced granular materials, and design guidance for granular base reinforcement and unsurfaced road construction using geogrids. Although not directly related to the application of geogrids for reinforcing railroad ballast, they do provide some insight into the mechanism by which they work.

33. Some of the most extensive laboratory tests investigating the use of geogrids for reinforcing granular base course materials have been done at the University of Waterloo, Waterloo, Ontario, Canada under the sponsorship of Tensar Corporation. The most comprehensive paper that addresses this research is "Granular Base Reinforcement of Flexible Pavements Using Geogrids" (Carroll, Walls, and Haas 1987) published in Geosynthetics '87 Conference Proceedings. Another technical paper describing this same test program is entitled "Geogrid Reinforcement of Granular Bases in Flexible Pavements" Haas, Walls, and Carroll 1988) published by the Transportation Research Board in Transportation Research Record No. 1188.

34. This research involved laboratory cyclic-load testing of unreinforced and geogrid reinforced base courses under thin asphalt pavements (3 to 4 in. asphalt surfacing). In addition to the presence of a Tensar SS1 geogrid reinforcement in the pavement system, other variables included base course thickness, reinforcement location, and subgrade strength. In these tests a 40 kN (9,000 lb) load was applied to the pavement through 300-mm (12-in.) diameter steel plate producing an applied pressure of 550 KPa

(80 psi). Each test section was subjected to a sequence of cyclic loads (8 cycles per second) followed by a single static load. Failure was considered to be the development of 20 mm (0.8 in.) ruts in the pavement. Details of the testing program, where a total of 24 separate tests were run, are given in the papers. Some of the important conclusions reached in this test program were:

- a. Grid reinforcement of the granular base course will reduce the permanent deformation in flexible pavement systems.
- b. Pavement sections having geogrid reinforcement in the granular base layer can carry increased numbers of load applications over unreinforced base sections. In this study the reinforced pavement section carried three times more load applications than the unreinforced pavement section before the failure criteria was reached.
- c. Grid reinforcement allowed from 25 to 50 percent reduction in the thickness requirements for granular base courses which was based on the load-deformation performance of the pavement systems.
- d. 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 of geogrid 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 layer over very soft subgrades.

An additional observation was that the strengthening effect of the geogrid in the pavement base course comes from the interlock with and confinement of the aggregate particles. Data from pressure cells near the surface of the subgrade in selected test sections with relatively weak (4 CBR) subgrades, (where the total deformation of the system was relatively small), indicated that the vertical pressure acting on the subgrade was reduced by approximately 22 percent during the early (first 10,000) load applications but gradually decreased to only about a 12 percent reduction after 150,000 load applications. In the test sections over very weak (approximately 1 CBR) subgrades, where large deformations occurred, the pressure cells did not indicate any pressure reductions for the reinforced section. In fact, a higher initial stress was measured in the reinforced section with the stresses gradually approaching those of the unreinforced section near the end of the test. It is believed

that for the very weak subgrades the stresses on the subgrade were not reduced until relatively large deformations occurred and the tensioned membrane forces were taken up by the geogrid reinforcement. These observations suggest that the interaction of the geogrid and the granular material affects the distribution of the stresses through the base course layer. Based on these test results and observations, these researchers concluded that pavements with geogrid reinforced base courses will either support more loads, or they can be built with a reduced base course thickness. Using the results of the test program, a design guideline for reducing the required base course thickness in a flexible pavement was developed and is presented in the Geosynthetics '87 Conference Proceedings (Walls and Galbreath 1987). The Tensar Corporation (1986a) has published a Technical Note entitled Granular Base Reinforcement of Flexible Pavements Using Tensar Geogrids that provides a brief summary of these test results.

35. The Transport and Road Research Laboratory (TRRL) of the United Kingdom's Department of Transport has conducted field tests to study the deformation of road foundations reinforced with geogrids. B. C. J. Chaddock (1988) in TRRL Research Report 140 discusses these tests and their results. In these tests various strength subgrades (0.4, 1.6, and 4.9 CBR) were covered with three different thickness ranges (110 to 220, 150 to 275, and 200 to 400 mm) (4.3 to 8.7, 5.9 to 10.8, and 7.9 to 15.7 in.) of compacted crushed limestone subbase. For each combination of subgrade strength and subbase depth, a geogrid reinforcement was placed under one-half of the section between the subbase and subgrade. The geogrid was placed so that both the unreinforced and reinforced sections were trafficked simultaneously. The sections were then trafficked with a two-axle truck having its dual-wheel rear axle loaded to about 80 kN (18,000 lb) until 40 mm (1.6 in.) of deformation occurred in the surface of the subbase.

36. This study provides a significant amount of useful data on the performance of geogrid reinforced granular bases under actual truck traffic. Conclusions drawn from this study included:

- a. For subgrade CBR values between 1.5 and 5, the presence of the geogrid between the subbase and the subgrade allowed approximately 3.5 times more traffic to be carried before the deformations reached the 40 mm maximum deformation criteria.
- b. The same performance under traffic would be obtained with a geogrid reinforced subbase having approximately 50 mm

(2 in.)less granular material than the corresponding unreinforced section.

- c. On the very soft (0.4 CBR) subgrade very little reinforcement of the subbase occurred. This was apparently due to the migration of the clay subgrade up through the apertures in the geogrid preventing geogrid-aggregate interlock. Chaddock points out that the reinforcement might have been more effective if some of the subbase material had been placed on the subgrade prior to the installation of the geogrid.

37. It is interesting to note that the reinforced sections in this field test supported over three times the number of axle loads before reaching the maximum deformation criterion. This corresponds well with the laboratory test results from the University of Waterloo study reported by Carroll, Walls, and Haas (1987, 1988) on reinforced base courses beneath thin asphalt pavements where approximately three times the number of load applications was carried by the geogrid reinforced pavement. Chaddock (1988) also suggests that approximately 50 mm of granular material could be replaced by geogrid reinforcement of the base. The base course thicknesses used in his study amount to base thickness reductions of 12 to 45 percent. Again, these amounts of thickness reductions due to the influence of the geogrid correspond with the base course thickness reductions observed in the University of Waterloo study for reinforced granular base courses under thin asphalt surfaces.

38. Unpublished data from a 1987 WES test section indicate improved performance of aggregate surfaces when reinforced with a geogrid. This test section consisted of 4 in. of crushed limestone over a firm (15-20 CBR) subgrade. Reinforcement consisting of one light nonwoven geotextile, four woven geotextiles (various strengths), and Tensar SS1 geogrid was placed at the aggregate-subgrade interface in six different test sections while one section contained no reinforcement. Three different traffic lanes ran the length of the test sections so that each section received the same type and amount of traffic. Traffic included a 30,000-lb C-130 aircraft tire, a 5-ton truck (32,000 lb rear tandem axle load) and a 140,000-lb tank. For a 2 in. rut depth failure criteria (3 in. rut for the tank), the geogrid reinforced section carried just over twice the number of passes than did the unreinforced section. While the improvement of the reinforced section was not as great under the aircraft loading, there was some improvement in performance.

Additional field tests on low strength subgrades are planned but have not been funded at this time.*

39. Other laboratory test programs investigating the performance of aggregate fills over soft subgrades have been reported by Milligan and Love (1985) and by Jarrett (1986). These papers report tests on unreinforced and reinforced fills using a single load application and plane strain conditions. Results indicate improved performance of granular materials over very soft subgrades when the granular materials are reinforced with a geogrid.

40. Review of the available literature indicated two design procedures of the design of unsurfaced roads using geogrids. The first, developed by Giroud, Ah-Line, and Bonaparte (1985), is presented in a paper that was presented at the Conference on Polymer Grid Reinforcement in London. The paper entitled "Design of Unpaved Roads and Trafficked Areas with Geogrids" (Giroud, Ah-Line, and Bonaparte 1985) gives the concepts and behavior of unpaved roads and other traveled ways, looks at the mechanisms by which geogrids can improve the performance of these structures, and provides an analytical method for determining the thicknesses of unreinforced and reinforced granular base courses. It is pointed out in the paper that geogrids can improve the performance of the base layer by an interlocking action between the geogrid and the aggregate particles. This interlocking provides reinforcement which can prevent shear failure, reduce permanent deformations, and delay progressive deterioration of the base layer. Giroud, Ah-Line, and Bonaparte (1985) state that theoretical calculations using layered elastic computer programs show that the thickness of unreinforced unpaved structures can be reduced by 30 to 50 percent by using geogrids. However, they also state that these values must be used with caution since the design method had not yet been calibrated with full-scale test data. It appears that the full-scale test data reported by Chaddock (1988) also validates, at least in part, the design procedure presented by Giroud, Ah-Line, and Bonaparte.

41. A second design procedure has been published by Tensar Corporation to cover haul and access roads reinforced with geogrids. The Design Guideline for Haul and Access Roads Reinforced with Tensar Geogrids (Tensar Corporation 1986b) provides design guidelines for designing unpaved haul and access

* Personal Communication, March 23, 1990. Steve L. Webster, Research Civil Engineer, USAE Waterways Experiment Station, Vicksburg, MS.

type roads with geogrids. It is based on guidance developed and published by the US Forest Service of the design of unreinforced haul roads over weak subgrades. This procedure consists of determining the required thickness of unreinforced granular material for a known subgrade strength, axle load, and pass level, thereby determining the required thickness of reinforced granular material using a simple relationship between reinforced and nonreinforced. The last step is an economic analysis of both alternatives to determine the total savings (if any) of the reinforced alternative. This is a very simple procedure and the Tensar Corporation even provides a worksheet to aid in the calculations (Tensar Corporation 1987).

PART V: DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

42. From the information presented in the foregoing sections it is evident that the amount of available literature discussing geogrids for railroad track reinforcement is quite small. Also evident is the fact that only a limited amount of laboratory testing is the basis for most of these publications. The laboratory tests that have been conducted concentrated on the load-deformation response of the track system when geogrids were used to reinforce the granular ballast/subballast. The results and conclusions from these laboratory tests are summarized in Paragraphs 19 and 20 of this report. While laboratory testing indicates that geogrids are beneficial in reducing the permanent deformations of the ballast, it appears that no testing has been done to determine if geogrids installed in the ballast section are beneficial in reducing the vertical pressures that act upon the subgrade, thereby allowing a reduction in the total ballast/subballast thickness requirements. Conversations with professionals within the railroad industry and in academia indicate differing opinions as to the benefit of geogrids in reducing the vertical stress acting on the subgrade. While there may be some reduction in this vertical stress, the benefits have never been quantified in either laboratory or field tests.

43. Geogrids have been successfully used by a few commercial railroads to assist in strengthening the track in problem areas over very weak subgrades. The use of geogrids to assist in the rehabilitation of a section of track belonging to CSX Transportation has been discussed in previous sections. Another commercial railroad that has used geogrids is the Southern Pacific Railroad Company (SP). Conversations with the Chief, Geotechnical Engineer for SP, indicate that geogrids are used only in those locations where the subgrade is very wet and where obtaining proper compaction is difficult. In the specific problem areas where a geogrid is needed, it is placed between the subballast and the subgrade. The SP began using geogrids for site-specific applications about 4 years ago and has had good results with them.* The

* Personal Communication, November 13, 1989. Darrel J. Maxey, Geotechnical Engineer, Southern Pacific Railroad Company, San Francisco, CA.

Atchison, Topeka, and Santa Fe Railway Company have also used geogrids to solve specific track problems. They have installed geogrids in several locations where poor subgrade soils resulted in maintenance problems. Indications are that the geogrids have performed well and have reduced track maintenance requirements.* It should be noted that in none of these applications has there been reductions in ballast/subballast thickness.

44. A telephone conversation with a sales engineer for one of the leading geogrid manufacturing companies indicated that there are four major functions a geogrid can perform when placed in a railroad ballast. These functions are to provide lateral and vertical restraint to confine the ballast and resist decompaction due to lateral movement, separate dissimilar materials, provide a working platform over very soft subgrade soils, and provide a membrane support by going into tension at low strain levels. The possibility of vertical pressure reductions and reduction of ballast thickness when a geogrid was placed in the track structure was also discussed. The manufacturer believes that geogrids will reduce the vertical pressure due to train loadings that act on the subgrade but that no one knows how much reduction actually occurs. At this time, experience indicates that the thickness of the ballast/subballast layer should not be reduced due to the inclusion of a geogrid in the ballast/subballast and such ballast thickness reductions are not recommended by this manufacturer. However, in situations where a geogrid is used for reinforcing a subballast over very soft subgrades the geogrid will allow a thinner layer of subballast to achieve adequate compaction for supporting construction traffic. In this application the design guidelines for unsurfaced road construction are applicable and can be used to reduce the subballast requirements. In this situation the geogrid allows one to compact the subballast material and provide a firm working surface without losing 6 to 8 in. of material into the soft subgrade. The sales engineer pointed out that the benefit of using the geogrid occurs when the subgrade soil is weak. A geogrid will not increase the compaction (strength) of a granular material when the subgrade is strong.** This fact is evidenced by the results of the laboratory test presented in Part IV of this report.

* Personal Communication, January 15, 1990. Johnny Johnson, The Atchison, Topeka, and Santa Fe Railway Company, Albuquerque, NM.

** Personal Communication, November 1989. R. G. Carroll, Sales Engineer, Tensar Corporation, Morrow, GA.

45. A number of laboratory and field tests have been performed researching the function of geogrids in reinforcing both surfaced and unsurfaced pavements. These studies, which have been summarized previously, show benefits of geogrid reinforcement that include the ability to carry up to about three times as many load applications on a given thickness of granular material or a reduction in the thickness of granular material required to support a given level of traffic. Even though the beneficial effects of the geogrid in these highway/road applications are well documented, they cannot be extrapolated to railroad applications. Differences in construction materials, construction procedures, and loading regime make this extrapolation impossible. Unfortunately, there has been only limited research into the benefits of placing geogrids in the railroad track structure. The research to date has concentrated on the use of grids to resist ballast deformation and reduce track maintenance. Little or no research has been conducted to determine the benefits of placing geogrids in the track structure to reduce the vertical pressures, thereby reducing the ballast and/or subballast thickness requirements. It appears that this is an area where additional research is needed.

Conclusions

46. Based on the results of the literature review and personal conversations conducted during this study, a number of conclusions were reached concerning the use of geogrids in the ballast/subballast of railroad track. These conclusions are:

- 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 into the granular layer. There is 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.

Recommendations

47. A number of recommendations for the use of geogrids in the construction or rehabilitation of railroad track on military installations have been developed. Based on this study it is recommended that:

- a. Geogrids not be used on a wholesale basis in an attempt to reduce permanent deformation of the ballast. The low levels of rail traffic on military installations do not justify the inclusion of geogrids in the ballast section to reduce the rate

of permanent deformation. A track that is properly designed and constructed will, with routine maintenance, support the projected traffic levels for many years without excessive permanent deformation and need for reballasting and retamping.

- b. Geogrids not be specified or used for reinforcement in track construction over medium to strong subgrades. Geogrids will provide little or no benefit for these conditions.
- c. Geogrids be considered for use in the subballast over problem areas having very weak to weak subgrades. The primary function of the geogrid in this application will be to provide a working platform for obtaining compaction of the granular materials over the geogrid and supporting construction traffic. Appropriate procedures for the design of geogrid reinforced unsurfaced haul (temporary) roads can be used to determine the subballast thickness requirements for this application. This thickness of subballast required to support the construction traffic can be considered as part of the total ballast/subballast thickness requirement. The total thickness of ballast and subballast required to support the railcar loadings and meet minimum design requirements is determined from conventional design procedures such as those recommended in Chapter 22 of the American Railway Engineering Association (Manual For Railway Engineering 1989). The thickness of subballast required for the working platform can then be subtracted from the total thickness requirement to determine the additional granular material required to support the railcar loadings.
- d. Where geogrids are considered for potential use in the construction of a working platform over weak subgrades, an economic analysis of the benefit of the geogrids can be performed and the most cost-effective solution can be chosen.
- e. The thickness of ballast and subballast determined from conventional railroad track design procedures not be reduced due to the inclusion of a geogrid. There is not sufficient laboratory and field test data to justify this type of thickness reduction.
- f. Additional research involving laboratory testing and measurement of vertical pressures in reinforced and unreinforced railroad track sections be conducted. The purpose of this research would be to determine if a reduction in ballast depth is possible using geogrids. Additional in-service validation on the benefits of geogrids should also be performed at a facility such as the Association of American Railroads Transportation Test Center in Pueblo, CO.

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APPENDIX A

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APPENDIX B

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