INDEPENDENT REVIEW AND VALIDATION OF TENSAR'S MODIFIED 1993 AASHTO PAVEMENT DESIGN PROCEDURE AND VERIFICATION OF SPECTRAPAVE4-PRO™ SOFTWARE

Submitted to

Tensar®

2500 Northwinds Parkway
Suite 500
Alpharetta, GA 30009

By

Applied Research Associates, Inc.
100 Trade Centre Dr., Suite 200
Champaign, IL 61820
(217) 356-4500
Fax: (217) 356-3088

Ryan R. Berg & Associates, Inc.
2190 Leyland Alcove
Woodbury, MN 55125
(651) 735-7622
Fax: (651) 735-7629

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1. INTRODUCTION

1.1 PURPOSE, SCOPE, AND BASIS FOR EVALUATION

This report documents the independent review of the pavement design method for geosynthetic stabilization of the aggregate base course of flexible pavement structures developed by Tensar International Corporation (Tensar). The independent review also included validating that the calculations and results received from Tensar's SpectraPave4-PRO™ software are consistent and in accordance with the pavement design method in the American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures (AASHTO 1993).

This evaluation was conducted for the Tensar Spectra® Roadway Improvement System, which is depicted in Figure 1-1. The primary components of this system include:

- Tensar® TriAx® geogrids
- Aggregate base course
- Asphalt pavement
- SpectraPave4-PRO™ pavement design software

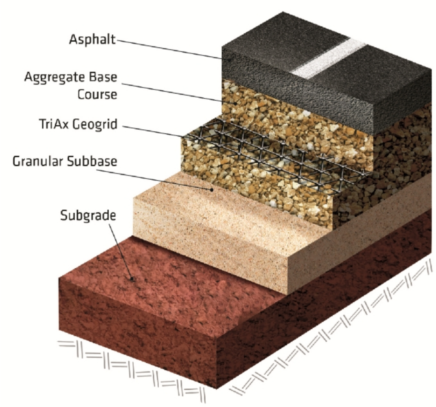

Figure 1-1. Cross sectional view of flexible pavement stabilized with Tensar TriAx Geogrid

The evaluation was conducted using material, design, construction, performance, and quality assurance information and data provided by Tensar, and evaluated for conformance to the criteria outlined in the protocol, attached in Appendix A. The protocol document substantially incorporates the Guide for Design of Pavement Structures and AASHTO R-50 Standard Practice for Geosynthetic Reinforcement of Aggregate Base Course of Flexible Pavement Structures (AASHTO 1993; 2010). Where no applicable criteria exist in the referenced documents, evaluations were based on the state of the practice, as indicated in the technical literature or documentation submitted by Tensar.

As noted in the Federal Highway Administration (FHWA) Geosynthetic Design and Construction Guidelines, geogrids are used in paved roadways in two primary application areas: base reinforcement (or, as Tensar more appropriately terms it, base stabilization) and subgrade stabilization (FHWA 2008). The scope of this evaluation is limited to the pavement optimization application of the Tensar SpectraPave4-PRO system.

This evaluation is intended for readers who have a working knowledge of the 1993 AASHTO design guide, mechanistic-empirical pavement design, geosynthetics, and construction of flexible pavements.

The results of this evaluation do not constitute an approval or a rejection of the system and/or its components. Further, any recommendations for modifications and/or conformance to specific evaluation criteria should not be construed as mandatory. The potential effects are noted, and each approval agency must determine its own requirements for implementation. It is suggested that designers note any deviation from this submittal when proposing Tensar's SpectraPave4-PRO design approach for acceptance by an approving agency.

1.2 General Applicability of Tensar Pavement Stabilization

The Spectra Roadway Improvement System is used to design and construct a mechanically stabilized base course layer within a flexible pavement system. The mechanically stabilized layer may be used in the pavement design to reduce the thickness of a pavement component, with the same target service life and performance, or to extend the pavement service life. Alternatively, these two options can be combined to provide both a reduction in component thickness and an extension of the service life in an equivalent cost solution that simply reduces the thickness of a pavement component to cover the cost of installing the geogrid.

The applicable range of asphalt layer and of base course layer thicknesses for the Spectra Roadway Improvement System is documented in this report.

1.3 Review Protocol

The protocol used for this review of a geogrid stabilized flexible pavement is presented in Appendix B. The items requested from the submitter are listed in the protocol.

2. HISTORY AND SYSTEM CONCEPT

The first integral geogrids, Tensar geogrids, were developed in the late 1970s and were first used in engineering applications in the early 1980s. Initial studies of enhancing performance of flexible pavements focused on reinforcing the asphalt layer with a biaxial geogrid and were reported in the proceedings of the 1984 Polymer Grid Reinforcement conference (SERC and Netlon 1985). The focus then switched to placement of the geogrid in the aggregate base course layer of a flexible pavement (e.g., Haas 1985).

The initial empirical-based flexible pavement guideline was presented as a graph of non-stabilized base thickness to an equivalent stabilized base thickness (Tensar 1986). The guideline noted that the geogrid should be placed at the bottom of base layers 10 inches or less in thickness and at the midpoint for thicker layers. A minimum base thickness layer of 4 inches was noted. Accompanying discussion noted that the geogrid could be used to decrease the base course layer thickness, decrease the asphalt layer thickness, or extend the pavement life. The stabilization benefits are also presented in a graph of layer reinforcement ratio (stabilized/non-stabilized) versus granular base thickness (Haas 1986; Tensar 1987).

The design procedures were updated and expanded in 1996 (Tensar 1996). These procedures follow the 1993 AASHTO Guide for Design of Pavement Structures. Procedures are presented for four options of benefits associated with incorporation of geogrids into a flexible pavement:

1. Extension of the pavement performance periods
2. Reduction of the base course layer thickness for an equivalent analysis period
3. A combination of 1 and 2—some extension of the performance periods and some partial reduction of the base course thickness
4. Increase in pavement reliability

Thus, the designer may opt to include the geogrid in the pavement design by use of a traffic benefit ratio (TBR) or a base course reduction factor (BCR). Life cycle cost analyses are recommended to quantify economic benefits.

The current pavement design procedures are presented in the SpectraPave4-PRO™ software. This software was first released in 1998 and has been updated regularly. This software contains procedures for both subgrade stabilization and pavement optimization. The temporary unpaved haul and access roadway design uses the Giroud-Han method (Giroud & Han 2004a; 2004b). This evaluation report focuses on only the pavement optimization design.

The SpectraPave4-PRO User's Manual states that the pavement optimization design module complies with AASHTO R-50, Standard Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures (Tensar 2011). This standard provides an outline of overall design considerations but does not provide step-by-step design procedures.

The SpectraPave4-PRO flexible pavement design module follows the empirically based 1993 AASHTO Guide for Design of Pavement Structures. The design approach uses enhanced layer coefficients to account for the benefits of the geogrid. These coefficients are based on extensive testing (laboratory, field, accelerated, etc.) and over 30 years of field performance. The coefficients are specific to the Tensar TriAx geogrids and are a function of the technical specifications of the geogrid, thickness of the asphalt layer, thickness of the aggregate base course, and subgrade strength.

The integral, extruded Tensar geogrids have been used extensively in aggregate base course layers since first introduced in the early 1980s. Section 3 of this report presents a summary of project case histories and of testing. Tensar geogrids have been used for base stabilization in pavements throughout the world.

2.1 POTENTIAL FUTURE ENHANCEMENTS

For future enhancement of the design procedure, Tensar is focusing on mechanistic-empirical (M-E) design procedures—specifically, how to incorporate the AASHTO Mechanical-Empirical Pavement Design Guide (MEPDG) procedures (AASHTO 2008). Discrete element modeling of geogrid and aggregate, mechanistic response modeling with finite element method analyses, full-scale testing, and laboratory testing are being employed to develop/refine an M-E design procedure.

3. LITERATURE REVIEW

Over the last 25 years, highway agencies, university researchers, and Tensar have conducted many research efforts to document the benefits of using mechanically stabilized layers (MSL) that incorporate a variety of Tensar geogrid products. These studies include laboratory testing, accelerated load testing, and construction of in-service pavement sections to determine the performance of incorporated geogrid materials into unbound layers, with the intent of improving pavement load-carrying performance. This section provides an overview of the results of these studies, relevant to the present study.

3.1 Laboratory Testing

Several studies documented improved material characteristics for unbound granular materials with geogrid enhancements when subjected to laboratory testing. Wayne, Kwon and Boudreau subjected unbound and mechanically stabilized aggregate specimens to resilient modulus and repeated load testing with test methods AASHTO T307 and National Cooperative Highway Research Program (NCHRP) 598, respectively (Wayne, Kwon & Boudreau 2010). Lower density samples with TriAx geogrid placed midway into the 12-inch-tall specimens performed similarly to higher density samples with no geogrid, indicating that geogrid placement may assist in lateral restraint of aggregate during compaction activities to improve the quality of aggregate layers. This study also presented results from the NCHRP 598 test that showed a specimen with geogrid performing better after 20,000 cycles than specimens without geogrid after 10,000 cycles. Figure 3-1 shows a plot of the control and geogrid stabilized material performance under repeated load. The TriAx geogrid sample appears to reach a stable point at 20,000 cycles, as opposed to the low-density specimen with no geogrid, which failed catastrophically after 10,000 cycles.

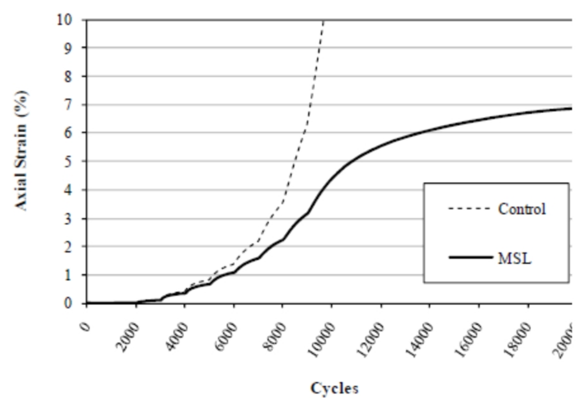

Figure 3-1. Repeated load deformation tests for unbound control aggregate and mechanically stabilized layer incorporating TriAx geogrid

Geogrid geometry and vertical position within the aggregate layer are two of the factors that determine the ultimate success of a geogrid, and these were investigated through a large-scale series of laboratory tests conducted in Louisiana (Murad & Chen 2010). This study included both biaxial and TriAx geogrids and positioned geogrids at the interface below the aggregate layer and above the subgrade, in the middle of the aggregate layer, and at the upper one-third point of the aggregate layer. The study also investigated applying prime coat to the top of the subgrade prior to placing geogrid at the interface. Cyclic load plate testing was conducted on specimens constructed within a 6.5- by 6.5-foot box in the laboratory, with testing conducted to two different "rutting" levels (0.75 and 1.0 inches). Repetitions to failure were determined for non-stabilized and geogrid-stabilized specimens, with TBRs ranging from 2.9 to 37.2 for rutting at 0.75 inches and from 1.5 to 7.4 for rutting at 1.0 inches. Findings of the study included better performance for TriAx geogrid versus biaxial geogrids and better results for the placement of the geogrid at the upper one-third depth versus mid-depth or at the bottom of the aggregate layer.

3.2 Field Demonstrations

Several reports documented the performance of geogrid-stabilized aggregate layers. Wayne, Boudreau and Kwon documented the performance of a TriAx geogrid placed in the middle of a 12-

inch layer of "crushed miscellaneous base" (CMB) for a pavement constructed at the Port of Los Angeles (Wayne, Boudreau & Kwon 2011). For this project, plate load testing was performed on the subgrade layer, the middle of the CMB (without geogrid installed), and on top of the full 12-inch CMB layer (with geogrid installed). The results of the field testing with the plate load indicated between 40 and 80 percent increase in the modulus of subgrade reaction, with the increase in modulus values being inversely related to the magnitude of the deformation achieved with the plate load test. In addition, laboratory testing of samples collected in the field showed the same behavior when tested under NCHRP 598, with the MSL samples surviving intact at up to 20,000 cycles, while the control (non-MSL) samples reached failure before 10,000 cycles.

Another field study conducted in California provides comparison data for two different Tensar TriAx geogrid products, TX160 and TX170 (Southern California Soil & Testing 2009). In this case, plate load testing and dynamic cone penetrometer (DCP) testing showed improved layer stiffness for both geogrid products when compared to a control pavement section with a non-stabilized aggregate base layer. This report also documents the relative cost benefit for the geogrid sections when compared to the control flexible section (savings resulting from reduced quantities of aggregate base material) and when compared to a section with cement-treated aggregate base (savings result from faster production and eliminating the cost of the cement treating operation). Assuming that the long-term performance of the pavement sections with geogrid is comparable or better than the performance of the control and cement-treated sections, these reduced costs will demonstrate a significant life cycle cost benefit in favor of incorporating geogrids into MSLs.

A project in North Dakota that incorporated TriAx geogrid materials into a layer of recycled salvaged base material was used to evaluate the appropriateness of using a layer coefficient of 0.10 for this layer, as opposed to the standard 0.14 for a high-quality base material (Wayne, White & Kwon 2010). In this study, field testing consisted of falling weight deflectometer (FWD) testing, DCP testing, and borehole shear testing, while laboratory resilient modulus testing was also performed. As expected, pavement sections with TriAx geogrid stabilization provided higher strength and modulus results than non-stabilized layers. The borehole shear testing provided an estimate of the lateral restraint provided by the geogrid materials placed at the bottom and in the middle of the recycled salvaged base layer. In the sections stabilized with TriAx geogrid, the lateral restraint was measured at over 200 psf, while 0 psf was measured in the non-stabilized sections. The presence of significant lateral restraint in the granular layer led to more isotropic behavior of the material, which leads to the higher strength and modulus values for the layer, resulting in thinner MSL base layers capable of carrying the same traffic as a significantly thicker unbound base layer (total pavement thickness for the control section was 44 inches, while the total pavement thickness for the MSL section was 26 inches). Laboratory testing of the materials from this project indicated a layer coefficient 30 percent higher than that allowed in the North Dakota pavement design procedure (0.13 versus 0.10).

For a section of Highway 905 near San Diego, California, two flexible pavement sections (one with a geogrid MSL layer and one without) were compared via a series of field and laboratory material characterization tests (Southern California Soil & Testing 2010). In this case, increases in the modulus of subgrade reaction, R-value, and resilient modulus values showed that the pavement section with the MSL should provide similar or better performance than the control, even though the control section consisted of more hot mix asphalt (HMA) (7 inches versus 6 inches), and more higher quality base material (29 inches of class 2 aggregate base (AB) versus 6 inches of class 2 AB and 11 inches of class 4 aggregate subbase (AS)).

Perhaps the longest duration field test of geogrid materials took place along Highway 99 in Sutter County, California (Reck 2010). This project was originally constructed in 1988 and included six different pavement sections, three of which incorporated geotextiles and geogrids. After 20 years, the section with lime treated base (LTB) is reported to be performing the best among the six sections, although FWD testing indicates that the section could be quickly approaching the end of its service life. The section that incorporated geogrid materials into an MSL has exhibited better performance than the other non-LTB sections, with respect to crack development, rutting, and pavement deflections. The geogrid section also performed in such a way over the 20-year evaluation period as to justify an increase in assumed R-value for the base layer from 15 to 40. Analysis of the geogrid pavement section indicates that the benefit associated with the MSL could also have been realized by reducing the Traffic Index (TI) from 10 to 7.5 or by increasing the aggregate base gravel factor from 1.1 to 2.2.

In Minnesota, Polk County CSAH 18 was constructed in 2000 using geogrid under an 8-inch Class V aggregate base under a 4-inch HMA surface (Howley & Sanders 2011). Without the geogrid, the pavement cross-section would have required a 12-inch Class V aggregate base to meet the design requirements for the expected traffic. Once the pavement was constructed, FWD testing indicated that not only would the pavement structure meet the 9-ton axle capacity requirement, but it was actually structurally capable of being designated as a 10-ton axle route. This paper also included a discussion of other research conducted for geogrid materials in the past, with a section on the residual stress developed between the geogrid and aggregate layer, which over time can lead to an increase in layer modulus/stiffness after repeated loading, rather than a deterioration of modulus/stiffness, as would be expected for a typical unbound aggregate base layer.

Another potential benefit to the use of geogrids is maintaining separation between the bottom of aggregate fill and the top of soft subgrade materials. Anderson described the mechanisms through which geogrids are able to provide stabilization and separation while still allowing filtration (Anderson 2006). The report includes a discussion of a project where sand aggregate fill was placed on very soft, mud subgrades near New Orleans, Louisiana; the presence of a geogrid at the aggregate-subgrade interface prevented contamination of the aggregate during construction and maintained this separation 13 years later.

3.3 Accelerated Load Testing

An evaluation of geogrid effectiveness was conducted using the accelerated pavement testing facility at the University of Illinois with nine different pavement sections (Al-Qadi et al. 2008). The test sections included in this evaluation consisted of a combination of two different HMA thicknesses (76 or 127 mm), three different base thicknesses (203, 305, or 457 mm), and various placement locations for the geogrid materials (none, bottom, top third, or bottom and top third). In general, this study found that the presence of geogrid materials in the MSLs significantly reduced the deflection observed at the top of the subgrade layer (improved rut resistance) and the transverse strain experienced by the HMA layer (improved crack resistance). The positive impacts attributed to the incorporation of the geogrid materials were found to be dependent on the overall stiffness of the pavement section, with more benefit observed for weaker conditions (softer subgrade and/or thinner base layers). Placement of the geogrid materials was also found to be significant, with no added benefit noted when two geogrid layers were used (top third and bottom of base layer) when compared to a single geogrid placed at the top third point of the base layer.

The U.S. Army Engineer Research and Development Center evaluated the performance of a Tensar geogrid used for base reinforcement in a thin, flexible pavement (Jersey et al. 2012). Three test items—one geogrid-reinforced test item and two unreinforced control test items—were constructed under controlled conditions. The test pavements were subjected to accelerated trafficking to evaluate the relative performance of the various pavement structures. Permanent surface deformations and pavement stiffness were measured periodically throughout traffic testing. The authors reported that the geogrid reinforced pavement section significantly improved the resistance to rutting. Further, the 2-inch asphalt concrete-surfaced geogrid reinforced test item provided more resistance to rutting than did the 3-inch asphalt-concrete-surfaced unreinforced control test item. Lastly, the computed TBRs indicated that the triaxial geogrid used in the study should extend the service life of the pavement significantly.

4. MATERIALS AND MATERIAL PROPERTIES

The materials used in the Tensar Spectra Roadway Improvement System are asphalt, aggregate base course, and geogrid. The pavement structure is founded on a subgrade material, and the pavement structure may also include a subbase material component. These materials are discussed below in relation to documented testing (see section 3), to material specifications (see section 6), and the inference space of the Spectra Roadway Improvement System.

4.1 Asphalt

The paved road portion of the SpectraPave4-PRO system is applicable to flexible pavements. There are no special asphalt material requirements or construction requirements for the use with the system. Therefore, standard asphalt material and construction specifications can be used.

The thickness of the asphalt component of the pavement is a design consideration, as discussed in section 5.

4.2 Aggregate Base Course

Generally, standard base course material and construction specifications can be used with the Spectra Roadway Improvement System. The material should be durable, well graded, and relatively free draining. A well-graded material with a limit on the top size should be specified and used to ensure interlock with the geogrid and achievement of design goals. A Tensar-defined preferred base course gradation is listed in Table 4-1. Cases outside of the preferred range will require that users contact the manufacturer.

Table 4-1. Preferred base course gradation (Tensar 2009b)

Size	% Passing
1½ in. (37.5mm)	100
¾ in. (19.0mm)	50–100
#4 (4.76mm)	25–50
#40 (0.42mm)	10–20
#100 (0.149mm)	5–15
#200 (0.074mm)	< 10

4.3 Subgrade

There are no special subgrade material or preparation requirements for use with the Spectra Roadway Improvement System. Stabilization benefits are realized on soft to very stiff subgrades. However, the design is a function of subgrade strength (as discussed in section 5), and the base stabilization benefits decrease with increasing subgrade strength.

4.4 Subbase

A subbase pavement component can be used with the Spectra Roadway Improvement System. There are no special subbase material or preparation requirements, unless a geogrid is used to provide stabilization of the subbase material during placement and compaction. In that case, a limit on the top size should be specified and used to ensure interlock with the geogrid.

4.5 Geogrid Stabilization

The Spectra Roadway Improvement System uses an integral geogrid that is manufactured by punching and stretching an extruded sheet of polypropylene. Prior to 2009, the Spectra system used a Tensar biaxial geogrid. After more than 6 years of research and development, Tensar introduced TriAx geogrid into North America in 2009. Tensar has since demonstrated, through a series of rigorous comparative laboratory and field tests, that TriAx functionally outperforms the old generation biaxial geogrids.

The key parameters that impact the performance of geogrid materials are the profile of the rib section, junction efficiency, aperture size, aperture shape, and the radial in-plane stiffness. The TriAx geogrid was developed to improve aggregate interaction and confinement. These improvements are expected, in turn, to improve the structural performance of the MSL.

5. STABILIZED PAVEMENT DESIGN

All pavement design essentially involves solving a single problem—design a system of layers that will provide the longest service life for a given level of traffic over subgrade soils of measured or assumed strengths, all for the least amount of money possible. In many cases, the load-carrying component of a flexible pavement structure consists of one or more layers of granular materials placed on top of the variable and weak subgrade, with a wearing course of HMA on top of the granular layer to provide a smooth, water-resistant surface. The objective of using geogrid materials in MSLs is to enhance the stability of the unbound, granular material so that thinner layers can be used (saving money on material purchase and placement costs) or a longer service life can be expected (saving money on future maintenance, rehabilitation, and reconstruction costs).

5.1 Mechanistic-Empirical Pavement Design

The current state-of-the-art tools in pavement design are M-E methodologies such as those incorporated into the AASHTO MEPDG (AASHTO 2008). In M-E pavement design, all layers in a pavement structure are assigned engineering material properties such as modulus and Poisson's ratio. Surrogate testing (California Bearing Ratio, R-value, etc.) for engineering properties can be used and correlated to engineering properties. The engineering properties are subjected to traffic loading using layered elastic, finite element, or other pavement modeling tools. The resulting stresses, strains, and deformations are then used in transfer functions that relate the mechanistic outputs to actual pavement performance.

Mechanically stabilized layers constructed with geogrid materials are intended to increase the material strength or the deformation characteristics for the unbound granular layers, leading to improved pavement performance. Incorporating these MSLs in M-E pavement design methods will require modification to the engineering properties and/or the transfer functions to account for the improved performance.

5.2 Recognition of Primary Distresses

A benefit of M-E pavement design is the recognition of how different pavement distresses manifest in the pavement section over time. Empirical pavement design methods based on the overall serviceability of the pavement, like the 1993 AASHTO methodology, do not recognize the distresses that lead to the pavement losing its serviceability. The Tensar SpectraPave4-PRO pavement design method does accommodate the distinct performance differences in performance by dividing the design into thin asphalt, standard asphalt, and thick asphalt pavements. The SpectraPave4-PRO method specifically states that comparisons between designs across these boundaries are not appropriate.

Thin asphalt pavements are defined in the SpectraPave4-PRO system as those less than 3 inches thick. In this configuration, the stresses in the asphalt layer are primarily compressive. As there is little asphalt in this type of pavement, the pavement loads must be carried primarily by the aggregate base and subbase layers. The key distresses that manifest are rutting and deformation in the subgrade and base layers. Stability in the subgrade, subbase, and aggregate layers is critical in thin asphalt pavements, and the MSL has a large impact on pavement response and performance. Figures 5-1 through 5-3 are schematics representing general flexible pavement behavior under applied loading. These were generated using engineering expertise and observations over thousands of analyses with permutations of asphalt thicknesses and subgrade stiffness, stress/strain ratios, and published damage algorithms. Figure 5-1 shows a schematic of the key distresses in a thin pavement section, showing that fatigue cracking is not a significant concern and rutting becomes the predominant distress.

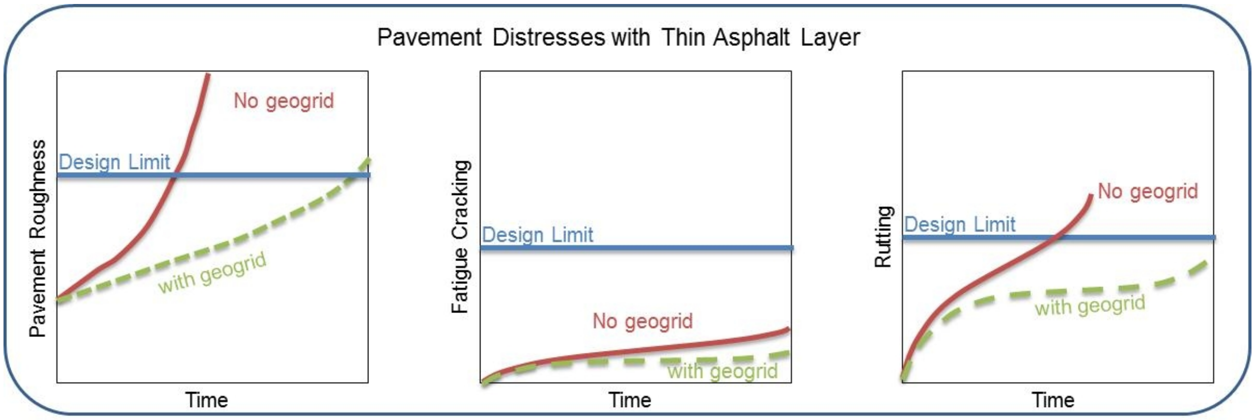

Figure 5-1. Pavement distresses with thin asphalt layers

The SpectraPave4-PRO method defines standard asphalt pavements as having an asphalt pavement thickness between 3 and 6 inches. This range covers many of the in-service local roads in the U.S. In this standard configuration, the asphalt is carrying a significant amount of the traffic loading, and it carries that load in both compression and in bending. As a result of the bending, asphalt fatigue becomes a concern, and the overall pavement performance is driven by the fatigue cracking in the asphalt layer and rutting that accumulates in the subgrade, base, and asphalt layers. Figure 5-2 shows a schematic of the key distresses in a standard pavement section, showing that fatigue cracking and rutting both contribute to the overall pavement performance.

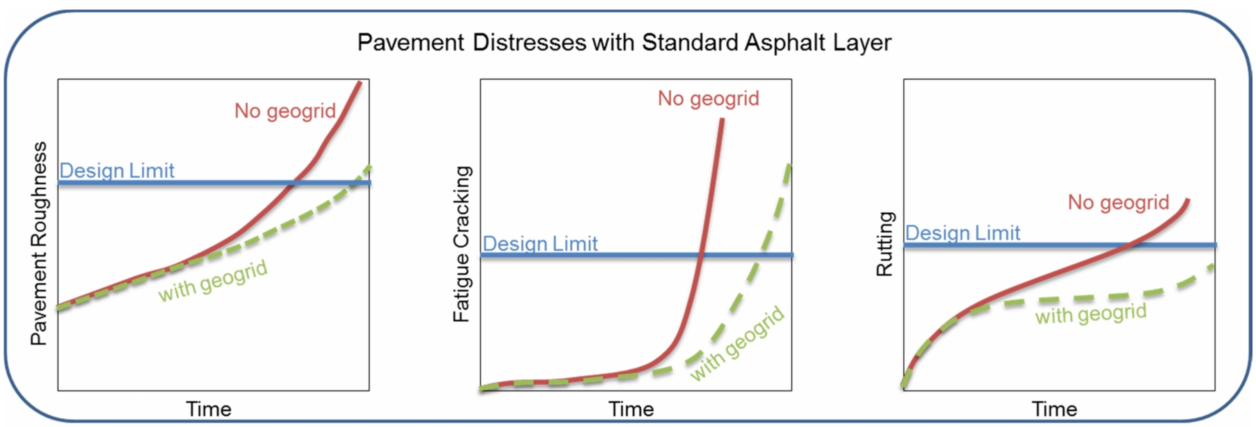

Figure 5-2. Pavement distresses with standard thickness asphalt layers

When asphalt thicknesses are greater than 6 inches, the SpectraPave4-PRO method defines the pavement as a thick asphalt pavement section. In a thick asphalt pavement, the primary load-carrying layer is the asphalt layer. As the asphalt layer thickness increases, the amount of bending strains in the asphalt decreases and the amount of fatigue cracking decreases. As the load is carried by the asphalt layer and the fatigue cracking is reduced, the distresses that drive performance become the asphalt layer rutting and some aggregate base and subgrade rutting. Figure 5-3 shows a schematic of the key distresses in a thick pavement section, showing that fatigue cracking is not a significant concern and rutting becomes the predominant distress. Also in this pavement type, the top-down cracking and durability of the asphalt layer tend to have a large impact on overall pavement performance.

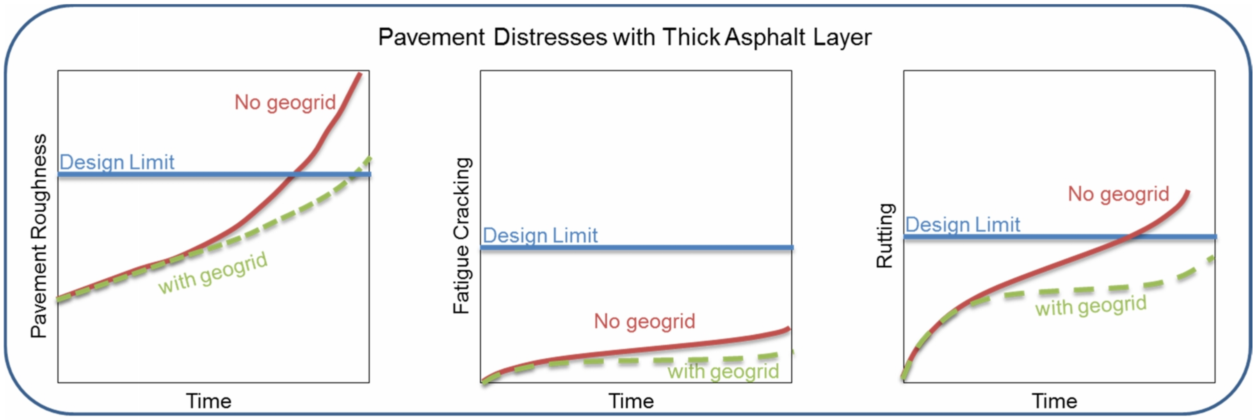

Figure 5-3. Pavement distresses with thick asphalt layers

5.3 TENSAR SPECTRAPAVE4-PRO™ METHOD OVERVIEW

The Tensar SpectraPave4-PRO tool is built on the pavement design methodology incorporated in an older (but still widely used) AASHTO pavement design procedure, last updated in 1993. The AASHTO 1993 flexible pavement design procedure assigns layer coefficients to each layer above the subgrade, including HMA and unbound granular layers. These layer coefficients are used to weight the actual thickness of a pavement layer to generate the effective thickness of a pavement structure, which is then evaluated against the required effective thickness based on expected traffic and subgrade conditions (the more traffic and/or the softer the subgrade, the more effective thickness is needed).

The layer coefficients used in the AASHTO 1993 pavement design methodology anticipate certain levels of material strength (as indicated by modulus, California Bearing Ratio, etc.) based on the category and type of material in a given layer. The SpectraPave4-PRO design procedure takes material properties for MSLs using only Tensar TriAx geogrid materials and increases the layer coefficients for those layers based on the anticipated increase in strength and durability for the MSL. At this time, increasing the layer coefficient is a technique that should only be applied when using Tensar TriAx, as no other products have had this technique validated through accelerated pavement testing. By increasing the layer coefficients for unbound, granular layers in flexible pavements, agencies should be able to reduce the amount of material needed in the aggregate base and/or asphalt layers to adequately carry the anticipated design traffic, or increase the amount of traffic (and associated service life) that a given layer thickness can provide and benefit from lower future maintenance, rehabilitation, and reconstruction costs for the pavement section.

5.4 MECHANICALLY STABILIZED LAYERS OF AGGREGATE

The factors that impact the increase in layer coefficient for the MSL include:

- Aggregate thickness
- Aggregate quality
- Location of geogrid
- Asphalt thickness (thick vs. thin)
- Magnitude and thickness of aggregate confinement
- Subgrade strength or resilient modulus
- Grade of geogrid

To better understand the confinement zone and its impact on the performance of the MSL, see the graphic representation in Figure 5-4. The aggregate that is directly above the geogrid is confined, and this confinement results in a decrease in lateral stresses. As the distance from the geogrid increases, there becomes a transition zone where there is partial confinement. When the distance from the geogrid is too great, the magnitude of the confinement goes to zero because the aggregate is too far from the sphere of influence of the geogrid. The Tensar SpectraPave4-PRO system recognizes these zones and the factors that impact MSL performance and incorporates these in the pavement design method.

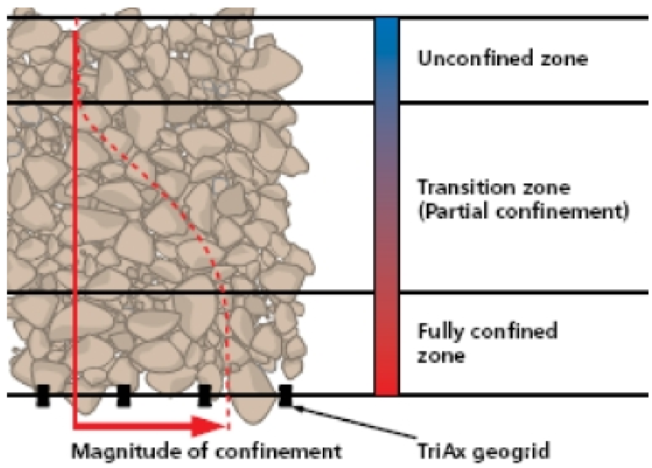

Figure 5-4. Representation of the magnitude and zones of enhanced confinement in an MSL

Even with the benefits that can be realized by using geogrid materials in constructing mechanically stabilized layers, agencies will still need to evaluate the cost savings resulting from thinner pavement layers or longer service lives against the added costs of acquiring and properly placing the geogrid materials as part of the pavement construction process. Another area where geogrids are likely to provide benefit is in improving the performance of lesser-quality granular materials (such as recycled, crushed HMA and/or portland cement concrete pavement), allowing more readily available, less expensive materials to be used in situations where their material properties would not be acceptable without incorporation into an MSL. These lesser-quality materials are also likely to be more variable than standard materials, providing another potential benefit for geogrids since they will be able to provide more uniform results with more variable materials, in general (Wayne, White & Kwon 2010).

In areas with a weak subgrade that is prone to mixing with aggregate layers placed directly on the subgrade, the enhanced separation provided by a geogrid can maintain the original thickness of uncorrupted aggregate material for a longer period of time, providing as-designed support and as-designed performance. Over time, mixing of the bottom of the aggregate layer and the top of the subgrade, particularly during times when the subgrade has high moisture and low strength, results in a layer of fouled aggregate base. This fouled layer has lower stiffness than the original aggregate base, and it has the effect of decreasing the thickness of the aggregate base layer. As Figure 5-5 shows, the stiffness of the base layer is maintained at higher levels over time with the use of geogrid, resulting in improved pavement performance (Wayne, White & Kwon 2010).

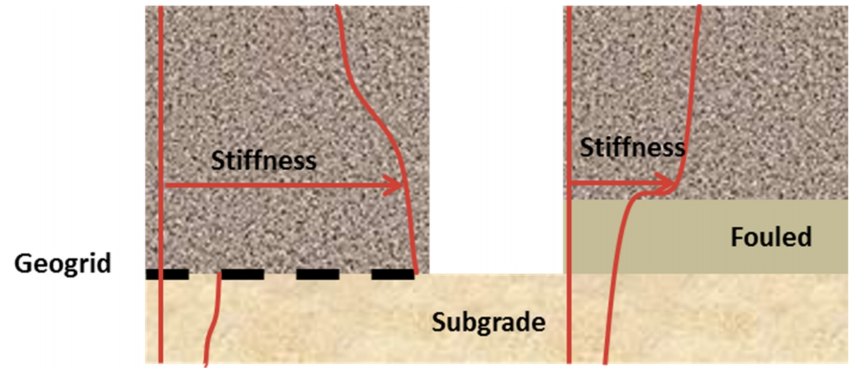

Figure 5-5. Schematic of aggregate base stiffness for pavement with geogrid and without geogrid after years of in-service pavement use

6. SPECIFICATION

6.1 PAVEMENT MATERIALS

As discussed in section 4, there are no special asphalt, subbase, or subgrade material requirements or construction requirements for the use with the Spectra Roadway Improvement System. Therefore, standard agency or owner asphalt, subbase, and subgrade material and construction specifications can be used. Likewise, standard base course material and construction specifications generally can be used. The base course material should be well graded, with a specified limit on the top size to ensure interlock with the geogrid soil reinforcement. Table 4-1 showed a Tensar-defined preferred base course gradation.

6.2 GEOGRID SPECIFICATION OPTIONS

AASHTO, FHWA, Geosynthetics Materials Association (GMA), Tensar, and other organizations provide recommendations for specification of geogrid pavement stabilization. Key points from the AASHTO, FHWA, and GMA references are summarized below. The Tensar recommendations are discussed in the following section.

AASHTO R 50-09 Standard Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures states that the engineer may want to develop an approved list of products that are considered appropriate for this application, based on successful past applications and long-term performance (AASHTO 2010).

The FHWA example geogrid pavement stabilization specification is from the GMA White Paper II (Holtz et al 2008; GMA 2000). Material property requirements are listed in this specification. Benefits of pavement stabilization may be incorporated into a design using a TBR, BCR thickness, or a modified layer coefficient ratio (LCR). Products submitted as equivalent shall have documented equivalent or better performance in pavement stabilization in laboratory tests, full-scale field tests, and completed project experience for the project conditions (base course material and thickness, failure criterion, subgrade strength, etc.). Products submitted as equivalent shall have a documented design benefit (TBR, BCR, or LCR) value equal or greater than the value used in the pavement design. Furthermore, it is noted that equivalent material description may not be desired, or required, if more than one geogrid is listed on the approved products list or if a single geogrid is bid against a thicker unstabilized pavement structure option.

6.3 TENSAR GUIDE SPECIFICATION

The Tensar guide specification is attached in Appendix C. This specification is accessed with the SpectraPave4PRO software. The highlighted designer/specifier numerical input values are captured from the program design input.

This guide specification provides three primary options for design and construction of the base course layer: mechanically stabilized layer, chemical stabilized layer, and unbound aggregate layer. The MSL option includes, but is not limited to, use of a geogrid system. The pavement design uses a modified LCR to incorporate the benefits of the MSL. The guide specification lists one approved manufacturer of the geogrid—Tensar—and the material properties to be certified by the manufacturer are for Tensar TriAx geogrids. The guide specification notes that acceptance of alternate geogrids shall not be based upon index (in-air) testing properties.

It is stated that the MSL option alternate geogrids materials must be submitted 2 weeks prior to the project bid date. The submittal shall contain (1) a design signed and sealed by a professional engineer registered in the project State and (2) a written statement from the engineer-of-record that the MSL design is based on the AASHTO 1993 methodology and that it utilizes a properly calibrated and validated modified layer coefficient.

6.4 Author's Review of Tensar MSL Specifications

Both the GMA and the Tensar specification guides have provisions for an agency to accept an equivalent or better product. From a practical standpoint, there are two significant obstacles for an agency to implement the use of such an approach. First, the detailed review required for an agency to determine equivalency is onerous, and there are no evaluation guidelines for an agency to follow. The documentation of laboratory test, full-scale tests, and completed project experience will not be equal for different products. Furthermore, the interpretation of all the test results and quantification of modified LCRs is, to some extent, subjective.

Second, there is not an allowance to use a product that is deemed useable but not equivalent or better. Is an alternate design, with different geogrid and thicker base course, acceptable? If so, the specification needs to address how this option is allowed.

Based on this review, the Tensar guide specification could be enhanced with the addition of the following items:

- Under Section 1.01, C Related Sections and/or under Section 2.02A Materials – The top size of the base course gradation should be specified and/or the preferred gradation (see Table 4-1) listed.
- Under Section 1.04A-Option A, 1.05A, F. – A third requirement should be added for MSL alternate geogrid: *The alternate geogrid modified layer coefficient calibration and validation shall be evaluated by a third party. An assessment report, by the third party, shall accompany the submittal, and with a qualifications summary of the third party reviewer.*
- Under Section 1.04A-Option A, or as an Option D – An additional option of an MSL with a geogrid that is not equivalent or better could be added.
- Under Section 1.06A Submittals, Item B – Certification from the manufacturer of the geogrid properties is noted. This could be enhanced by stating that certification must be signed by an officer of the manufacturing company.
- Under Section 2.02A Materials, Item C – The listed geogrid properties are dimensional and appropriately are nominal values. The specification should be enhanced with the addition of some minimum values of structural properties, to ensure manufacturing quality of the triaxial geogrid. Properties could include ultimate tensile strength, junction efficiency, aperture stability, and/or radial stiffness.
- Under Section 2.02A Materials, Item C – The listed geogrid properties are dimensional and appropriately are nominal values. The specification should be enhanced with the addition of properties listing for the resin used in manufacturing of the geogrid.

7. QUALITY CONTROL/QUALITY ASSURANCE SYSTEMS

Quality control and quality assurance (QC/QA) programs have been developed for the manufacture of the triaxial geogrids, pavement design, and construction. Each plan was reviewed separately, as discussed in the following subsections.

7.1 TRIAXIAL GEOGRIDS

A QC/QA Manufacturing Procedures for Tensar Triaxial Geogrids program manual, November 9, 2012, was submitted, which provides all Tensar-related testing and acceptance limits. Maximum, minimum, or nominal (as applicable) property limits are provided. Production QC checks and post-manufacturing QA testing are listed. Tensar requires documented QC/QA on each production lot. Manufacturer certification of product delivered to a project is addressed in the Tensar guide specification and is discussed in section 8 of this report.

7.2 DESIGN QC/QA

Design of Tensar Triaxial geogrid stabilized aggregate layer is performed with the Tensar SpectraPave4 PRO[M] software for subgrade stabilization and pavement optimization applications. This is the first version of software specifically providing analysis for TriAx geogrids. QC of development of this software was accomplished by procedures outlined in Tensar's internal software quality review.

This report constitutes an extensive QA process on the SpectraPave4 PRO software. The depth of this QA testing and validation is discussed in section 5.

QC/QA of project-specific pavement designs is the responsibility of project engineer, who should be a registered Professional Engineer. All calculations are checked by an engineer other than the designer. A registered Professional Engineer seals all drawings and calculations.

7.3 CONSTRUCTION AND QUALITY CONTROL MANUAL

An Installation Guide for the Spectra Roadway Improvement System, available on the Tensar website (www.tensarcorp.com) and within the software, was reviewed (Tensar 2009a). This is a complete guide for installation and promotes sound construction practices. This installation guide should be available for and used with every project installation, to ensure quality in the constructed works.

7.4 WARRANTIES AND INSURANCE

Tensar assumes responsibility for the application of the geogrid benefits to the pavement section for the specific conditions identified for the project. The owner is responsible for the properties of the components other than the geogrid and external stability, defined as the stability of the roadway against general failure including slope stability, geologic hazards, and settlements. Professional and product liability terms are as follows:

Professional Liability
Amount: $5M Aggregate
Deductible: $750,000
Basis: Claims Made
Insurer: Beazley

Effective Dates: October 1, 2012 - October 1, 2013

<u>Product Liability</u>
Amount: $2M Aggregate within General Liability Policy
$5M Aggregate "Umbrella" Policy within Excess Liability Policy
Deductible: $500,000
Basis: Claims Made
Insurer: Beazley (Product Liability) and Chartis Specialty Ins. Co. (Umbrella)
Effective Dates: October 1, 2012 - October 1, 2013

8. CONSTRUCTION

Design and construction of Tensar triaxial geogrid stabilized aggregate layer for paved roadways is applicable to the following:

- Flexible (i.e., asphalt-surfaced) pavements
- Asphalt layer thicknesses equal to or greater than 2 inches and equal to or less than 14 inches
- Aggregate subbase/base course thicknesses equal to greater than 2 inches and equal to or less than 14 inches or incorporation of additional layers of geogrid
- Subgrade, or subbase, with resilient modulus ranging from 5,000 psi to 15,000 psi

The guide specification, attached in Appendix C, addresses construction. Requirements for subgrade preparation, aggregate base placement, inspection, and repair are presented. This specification does not address aggregate material and compaction requirements; these should be covered in another project specification.

An Installation Guide for the Spectra Roadway Improvement System, available on the Tensar website (www.tensarcorp.com) and within the software, is attached in Appendix D. Commentary and photographic illustrations are provided. Topics of storage and handling, site preparation, geogrid placement and overlaps, placement on curves, cutting of geogrid, tensioning and anchoring of the geogrid, aggregate fill placement and spreading, aggregate base compaction, and special considerations are addressed. This guide promotes sound construction practices.

9. PERFORMANCE

There is significant documentation to describe the in-place performance of TriAx geogrid. Many States have already developed specifications for TriAx geogrids. To date:

- Specifications, design guidance, and/or approved/qualified products lists that include TriAx geogrid have been published in 23 States; and
- Also, TriAx geogrids have been approved for use on projects post-bid, through value engineering proposals, change orders, or as an approved alternate to the specified product in 12 additional states.

This includes specifications for TriAx geogrid as an acceptable pavement structure component by many states historically known for pavement design innovation.

As agencies move towards sustainable infrastructure while facing the constant mantra of “doing more with less,” TriAx geogrids can be a desirable pavement structure component. The use of TriAx geogrid will reduce the need for granular base/subbase material and, potentially, asphalt cement. Further, TriAx geogrid can be pulverized easily with base reclamation equipment. If a roadbed needs to be re-worked as part of a reconstruction to accommodate additional traffic or geometric constraints, the TriAx geogrid is easily disintegrated with the exact same base reclamation equipment; no further base layer preparation is needed. The TriAx geogrid easily separates into small pieces and gets redistributed in the base material with no continuity.

10. CONCLUSION

ARA reviewed Tensar's SpectraPave4-PRO™ software, user manual, and underlying calculations. We found the software to be compatible and consistent with the AASHTO R50-09 Standard Practice for Geosynthetic Reinforcement of Aggregate Base Course of Flexible Pavement Structures and the 1993 AASHTO Guide for Design of Pavement Structures. Using SpectraPave4-PRO™ to design pavement structures utilizing Tensar's TriAx geogrid follows sound and appropriate pavement engineering practice. The SpectraPave4-PRO™ software emulates the 1993 AASHTO flexible pavement design procedure and produces designs that are compliant with the methodology and the resulting pavement structure requirements.

ARA also reviewed Tensar's in-house research documentation. The documentation indicates appropriate experimental design and procedures. Tensar's in-house research appears to support the protocols and intent of AASHTO and FHWA standards (AASHTO 2010; FHWA 2008).

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1. APPENDIX A. METHOD FOR EVALUATION OF GEOGRID TECHNOLOGY

1.1 Incorporation of Geogrid in Pavement Design

To properly implement the use of geosynthetics in Empirical (AASHTO '93) or Mechanistic-Empirical (AASHTO DARWin ME) pavement design, the items described below must be performed either by or on behalf of the geogrid manufacturer/supplier. All performance based evaluations shall contain information that at a minimum must include the specific geogrid line[1] designation, and product designation within that line. For those cases where buy American is required by Federal Law a letter must be supplied with all design proposals documenting the geographic location of the manufacturing facility.

1.2 Performance Based Evaluations

1.2.1 Full Scale:

Full scale and accelerated pavement testing (FS/APT)[2] is required to demonstrate performance under moving wheel loads for a particular geogrid product line[3].

1.2.2 Large Scale Laboratory:

Large scale laboratory performance testing shall be conducted to demonstrate performance differences between the behavior of a geogrid evaluated in full scale testing and the product line[1] it represents. Use of this information to extend design attributes for additional members of a product line from those included in APT must be recorded within the independent review and validation report.

1.3 Design Requirements

1.3.1 Design Analysis/Value Engineering Proposals:

Pavement design proposals shall be performed under the direction of a licensed professional engineer by personnel who at a minimum have successfully completed their Fundamentals of Engineering exam. Further, the licensed professional engineer who reviews the proposal must be familiar with and registered within the state for which the proposals have been prepared.

1.3.2 Final Design Proposals:

At a minimum, final design proposals shall be sealed by a licensed professional engineer who reviews said proposal and is familiar with and registered within the state for which said proposals have been prepared. Performance based evaluations and independent review documentation must accompany all final design proposals.

1.4 PEER REVIEW

Peer review is required before a geogrid product line can be placed on a qualified product list or utilized in a design procedure that is different from that proposed by the manufacturer. Peer review requires that the design approach and supporting testing and field documentation be reviewed and a report generated by an industry recognized pavement engineering services firm. The third party shall be familiar with both the role of geosynthetics and pavement design principles, as well as, performance evaluation of pavements. Areas of expertise shall include at a minimum roadways, airfields, parking areas, and intermodal facilities. The peer review document shall accompany all final design proposals once complete.

[1]Geogrid product line is defined as a class of manufactured products that vary by no more than one product parameter. All other parameters remain the same with respect to the manner in which the elements associated with final product are assembled into a stable geometry. (e.g. sheet thickness for the case of punched and drawn geogrids or number of filaments for the case of woven or knitted geogrids)

[2]FS/APT shall consist of wheel loading conditions that are equivalent to or exceed an 18-kip single axle load.

[3]Design procedures which incorporate the benefit of a particular geogrid line shall require the supplier and/or manufacturer to demonstrate to the design engineer of record that full scale APT results for one or more products within that product line meet or exceed design results generated by said procedure.

2. APPENDIX B. SPECTRAPAVE4-PRO SOFTWARE EVALUATION

To perform the validation of the Tensar-modified '93 AASHTO pavement design method (as contained in the SpectraPave4-PRO software), ARA performed a series of pavement designs intended to validate that the results of SpectraPave4-PRO are consistent with results obtained using enhanced layer coefficients in the '93 AASHTO pavement design method.

Using the Tensar software, ARA verified the enhanced layer coefficients provided in the background documents. The enhanced layer coefficients included in the software are shown in Table 2-1.

Table 2-1. Enhanced Layer Coefficient Values as determined from SpectraPave4-PRO Software

MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
	5,000	6,500	8,000	9,500	11,000
6	0.273	0.271	0.269	0.267	0.265
8	0.247	0.245	0.243	0.240	0.238
10	0.231	0.229	0.227	0.225	0.223
12	0.216	0.214	0.212	0.211	0.209
14	0.205	0.204	0.202	0.201	0.199
16	0.197	0.196	0.194	0.193	0.192
18	0.191	0.189	0.188	0.187	0.186

2.1 TRAFFIC BENEFIT RATIO (TBR)

For each of the mechanically stabilized layers (MSL) aggregate thicknesses and subgrade resilient modulus' presented in Table 2-1, anticipated traffic levels until failure were calculated using the enhanced layer coefficients (to three significant digits). The TBR values were calculated for a thickness of 3" of HMA, 4" of HMA, 6" of HMA, 8" of HMA, and 10" of HMA, with the TBR simply defined as the ratio of allowable traffic loading until failure with geogrid over traffic loading to failure without geogrid. The results are presented in the tables below, with other inputs held constant for this evaluation, including:

Reliability	90%
Overall standard deviation	0.49
Initial Serviceability Rating	4.2
Terminal Serviceability rating	2.5

The goal of this analysis is twofold—1) Evaluate the reasonableness of the TBR values over the range of HMA thickness, aggregate thicknesses, and subgrade resilient modulus, and 2) Evaluate the trends in the TBR values compared to changes in subgrade modulus and MSL thickness.

The calculated TBR for 3" HMA layer thickness is presented in Table 2-2 and Figure 2-1.

Table 2-2. Calculated Traffic Benefit Ratio for 3" HMA Thickness

HMA Thickness (in)	MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
		5,000	6,500	8,000	9,500	11,000
3	6	6.6	6.4	6.3	6.1	6.0
	8	6.1	5.9	5.7	5.6	5.4
	10	5.7	5.5	5.3	5.2	5.0
	12	5.1	4.9	4.7	4.6	4.4
	14	4.6	4.4	4.3	4.2	4.0
	16	4.2	4.1	4.0	3.9	3.7
	18	4.0	3.9	3.8	3.7	3.5

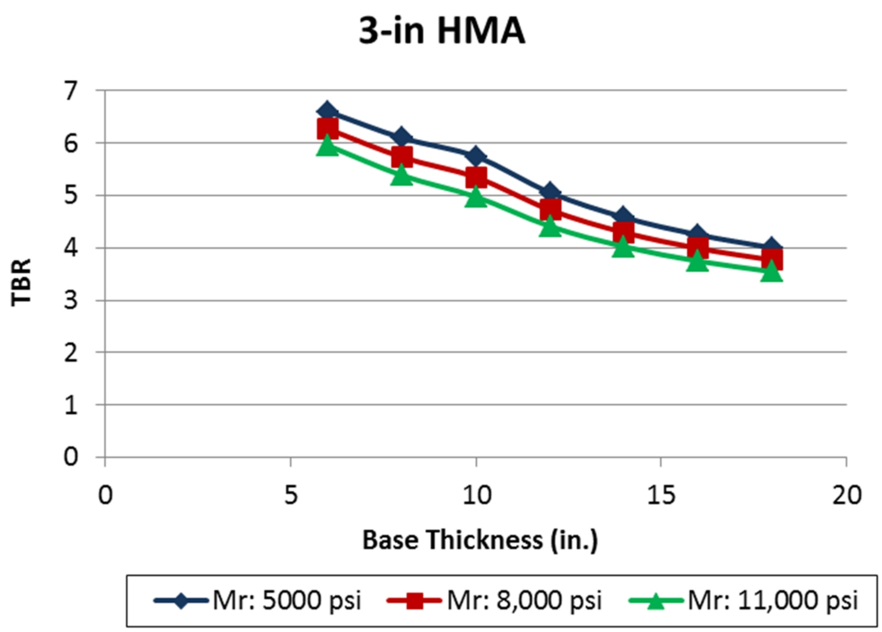


Figure 2-1 Calculated TBR Plot for 3" HMA Thickness

The calculated TBR for 4" HMA layer thickness is presented in Table 2-3 and Figure 2-2.

Table 2-3. Calculated Traffic Benefit Ratio for 4" HMA Thickness

HMA Thickness (in)	MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
		5,000	6,500	8,000	9,500	11,000
4	6	5.0	4.9	4.8	4.7	4.6
	8	4.8	4.7	4.6	4.5	4.3
	10	4.8	4.6	4.5	4.3	4.2
	12	4.4	4.2	4.1	4.0	3.9
	14	4.1	4.0	3.9	3.7	3.6
	16	3.9	3.8	3.7	3.6	3.5
	18	3.7	3.6	3.5	3.4	3.3

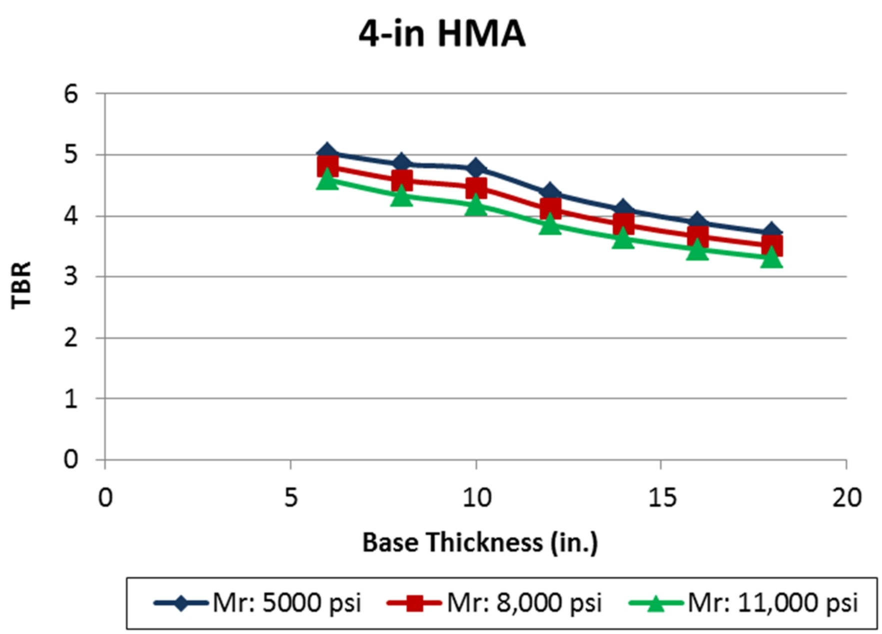


Figure 2-2 Calculated TBR Plot for 4" HMA Thickness

The calculated TBR for 6" HMA layer thickness is presented in Table 2-4 and Figure 2-3.

Table 2-4. Calculated Traffic Benefit Ratio for 6" HMA Thickness with thin HMA analysis

HMA Thickness (in)	MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
		5,000	6,500	8,000	9,500	11,000
6	6	3.7	3.6	3.5	3.5	3.4
	8	3.7	3.7	3.6	3.5	3.4
	10	3.9	3.7	3.6	3.5	3.4
	12	3.7	3.6	3.5	3.4	3.3
	14	3.6	3.5	3.4	3.3	3.2
	16	3.4	3.3	3.2	3.2	3.1
	18	3.3	3.2	3.1	3.0	3.0

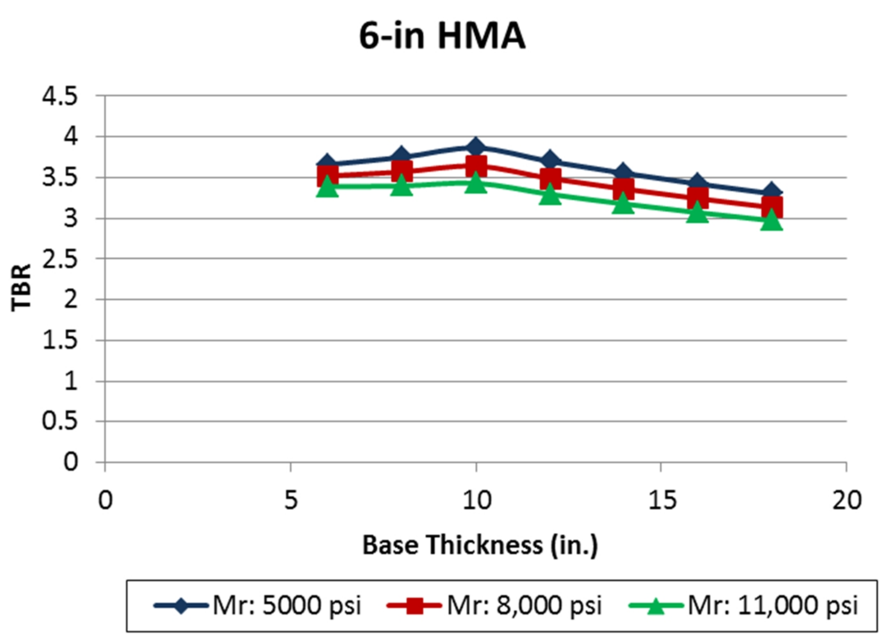


Figure 2-3 Calculated TBR Plot for 6" HMA Thickness with thin HMA analysis

The calculated TBR for 8” HMA layer thickness (the thick HMA layer) is presented in Table 2-5 and Figure 2-4.

Table 2-5 Calculated Traffic Benefit Ratio for 8” HMA Thickness with thick HMA analysis

HMA Thickness (in)	MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
		5,000	6,500	8,000	9,500	11,000
8	6	3.2	3.1	3.0	3.0	2.9
	8	3.3	3.2	3.1	3.1	3.0
	10	3.4	3.3	3.2	3.1	3.1
	12	3.3	3.2	3.1	3.0	3.0
	14	3.2	3.1	3.0	2.9	2.9
	16	3.1	3.0	2.9	2.8	2.8
	18	3.0	2.9	2.8	2.8	2.7

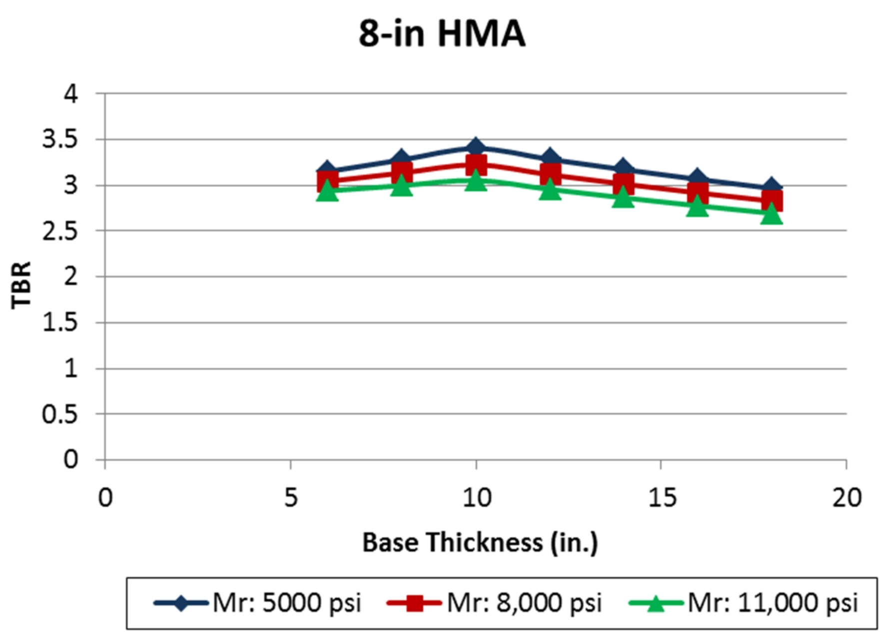


Figure 2-4 Calculated TBR Plot for 8" HMA Thickness with thick HMA analysis

The calculated TBR for 10" HMA layer thickness is presented in Table 2-6 and Figure 2-5.

Table 2-6. Calculated Traffic Benefit Ratio for 10" HMA Thickness

HMA Thickness (in)	MSL Aggregate thickness (in)	Subgrade Resilient Modulus (psi)				
		5,000	6,500	8,000	9,500	11,000
10	6	2.8	2.8	2.8	2.7	2.7
	8	2.9	2.9	2.8	2.8	2.7
	10	3.1	3.0	2.9	2.8	2.8
	12	3.0	2.9	2.8	2.7	2.7
	14	2.9	2.8	2.7	2.7	2.6
	16	2.8	2.7	2.7	2.6	2.5
	18	2.7	2.6	2.6	2.5	2.5

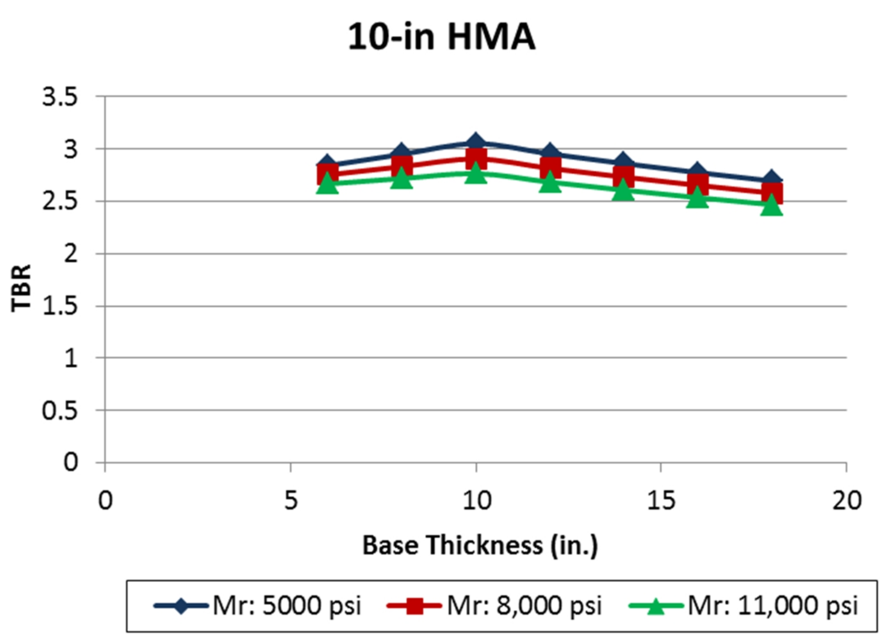


Figure 2-5 Calculated TBR Plot for 10" HMA Thickness

Figure 2-6 presents the TBR data for a 6-in aggregate thickness. This chart is used to review the overall trend in calculated TBR with changes in the HMA thickness and subgrade modulus.

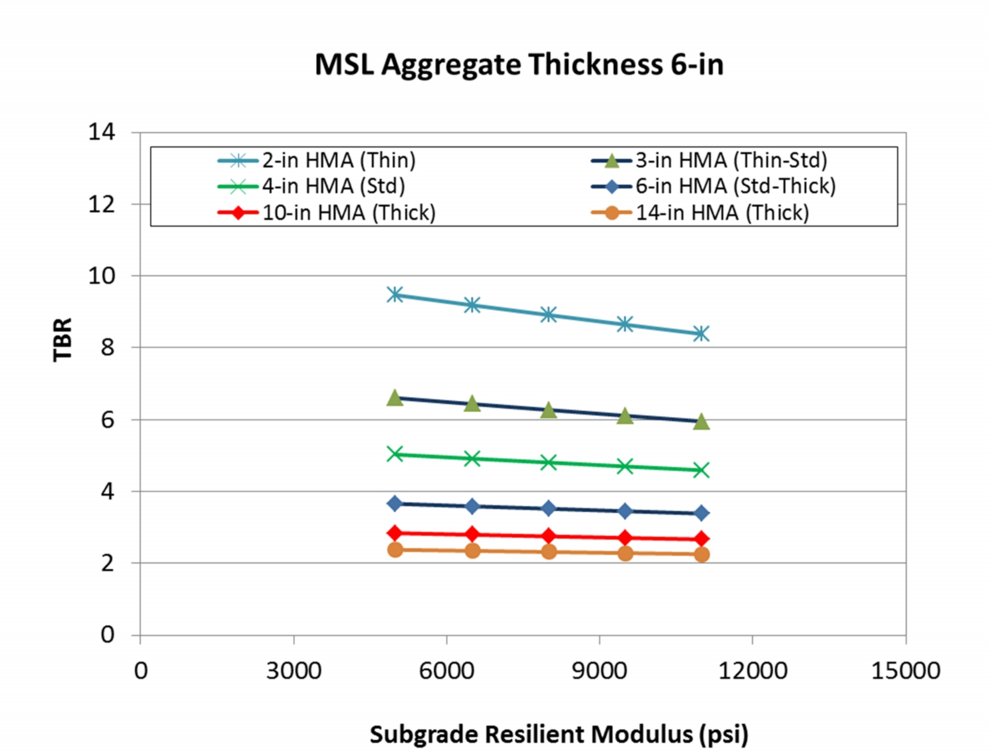


Figure 2-6 Calculated TBR plot for 6" aggregate thickness and multiple HMA thicknesses over a range of subgrade resilient modulus (M_r).

3. APPENDIX C. – GUIDE SPECIFICATION

GUIDE SPECIFICATION

Tensar Spectra System® for Flexible Pavement Applications

The specification provides guidance to designers on Tensar's recommended approach for incorporating the Spectra System™ technology into flexible pavement structures. ***By following this recommended approach and format, the intent of the SpectraPave4PRO design analysis and the integrity and reliability of the Spectra System technology is maintained by ensuring that critical parameters from the design and the technology are incorporated into the project contract documents.*** It is important to recognize that the Spectra System™ technology is proprietary and has been developed and established exclusively based on the performance delivered by patent-protected Tensar TriAx® TX5 and TX7 Geogrids. However, the specification approach suggested herein is generic and non-proprietary as it provides guidance on incorporating Spectra System into projects by using generic terminology, and by including alternative solutions based on other technologies. This approach is particularly appropriate for public agencies and/or private organizations that require multiple and non-proprietary alternatives to be included in bid documents.

References, definitions and related matters are updated or changed occasionally. For the most recent version of this specification please visit our website (www.tensarcorp.com). For technical assistance with Spectra System, including design assistance, please contact Tensar Technical Assistance (1-800-TENSAR-1) or your local Tensar representative.

This page contains notes to the specifier and should be deleted from the final specification.

Tensar International Corporation

May 2013

SECTION 00XX00
SPECIFICATION FOR AGGREGATE BASE LAYER CONSTRUCTION OPTIONS
FLEXIBLE PAVEMENT APPLICATIONS

1.0 GENERAL

1.01 SUMMARY

A. Section Includes – This specification covers the requirements for constructing the Aggregate Base Layer of the flexible pavement structures shown on the contract drawings. The work includes all materials, labor, equipment, storage, private lab testing, sampling, handling, excavation, disposal, tools, removal, placement, hauling, shaping, compacting, surveying, finishing to grade, curing, fees, permits, test-rolling and/or proof-rolling the aggregate including all appurtenances and incidentals necessary to complete the work. The properties and performance of the Aggregate Base Layer have been considered in, and are integral to, the structural design of the pavement section; therefore no modification of the pavement structure shall be made unless in accordance with the alternative stabilization methods described herein and/or the requirements for submission of alternatives described herein.

B. These specifications include provisions for three (3) alternative means of constructing the aggregate base layer. The Contractor may choose any of the three (3) options contained in this specification unless otherwise indicated on the plans or in the contract documents, and with the approval of the Engineer, may change to another option during the project at no additional cost to the Owner.

C. Related Sections
1. Section 02200 - Site Preparation
2. Section 02300 - Earthwork
3. Section 02700 - Bases, Ballasts, Pavements, and Appurtenances

1.02 DEFINITIONS

A. Mechanically Stabilized Layer (MSL) – A composite layer of a defined thickness comprised of aggregate or base course material combined with one or more layers of a polymeric geogrid. The geogrid shall be a regular network of integrally connected, multi-directional tensile elements of appropriate orientation, size and shape with triangular apertures of appropriate size and shape to allow interlocking with the unbound aggregate or base course material. The combination of the two materials creates a composite layer with improved properties and performance capabilities.

B. Chemically Stabilized Layer (CSL) – A composite layer of a defined thickness comprised of unbound aggregate or base course material combined with a chemical stabilizing agent that creates a composite layer with improved properties and performance capabilities.

C. Unbound Aggregate Layer – A layer of a defined thickness of unbound aggregate or base course material, installed by conventional methods and not modified or improved in any way. To achieve equivalent performance to a Mechanically or Chemically Stabilized Layer, an unbound aggregate layer will require greater thickness.

D. Subgrade Stabilization Application – Use of an aggregate layer immediately over a soft subgrade soil in order to improve the bearing capacity and mitigate deformation of the subgrade soil under repeated loads. The goal of this application may be to reduce undercut requirements, to improve construction efficiency, to reduce the amount of aggregate subbase/base material required, to provide a stiff working platform for construction traffic and site access, to achieve the required subgrade strength for a pavement design, or a combination of these.

E. Pavement Optimization Application – Use of an aggregate layer beneath or within the aggregate base course of a flexible (asphalt) pavement system to improve the stiffness of the system. The goal of this application may be to reduce the amount of aggregate or asphalt material required (reducing initial cost), increase the life of the pavement (reduce life-cycle cost), or a combination of the two.

2.0 AGGREGATE BASE LAYER OPTIONS

2.1A SYSTEM DESCRIPTION – OPTION A

A. Option A – Mechanically Stabilized Layer - This work shall consist of furnishing all materials, labor, and equipment for the construction of a mechanically stabilized aggregate base layer as detailed herein and shown on the plans, including aggregate material and stabilization geogrid. The Mechanically Stabilized Layer has been designed as an integral part of the pavement structure in order to achieve the required traffic capacity. Any deviation from the original design configuration must be approved by the Engineer as detailed below, and must demonstrate compliance with all relevant design requirements as determined by the Engineer.

2.1.1A DESIGN & PERFORMANCE

A. The design of the pavement shall be in accordance with the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures*, and *AASHTO R50-09, Standard Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures*.

B. The Mechanically Stabilized Layer within the pavement structure shall have a thickness of XX inches (XXX mm) or as shown on the contract plans.

C. The design of the pavement shall be based on the following parameters:
   a. Design traffic = XXXXXX ESALs
   b. Mechanically Stabilized Layer Structural Number = XXX

D. The MSL shall be incorporated into the pavement design by utilizing modified layer coefficients. Modified layer coefficients shall be calibrated and validated with the results of full scale laboratory, field and/or accelerated pavement testing where actual geogrids are tested within the pavement and in representative conditions.

E. In-air index testing of geogrid properties, or explanations of performance based on in-air index testing of geogrid properties, are not sufficient to understand the complex mechanisms involved in soil/geogrid interaction and/or the performance of MSLs. Therefore, no acceptance of alternates based on material property comparisons, or explanations of performance based on in-air testing of geogrid properties, will be permitted.

F. Any submittal for an alternative MSL design must be submitted at least 2 weeks in advance of the bid date and must be accompanied by the following:
   1. A design signed and sealed by a professional engineer registered to practice in the country, state or province in which the project is located.
   2. A written statement from the alternative MSL design engineer-of-record that the design is based on the AASHTO 1993 Pavement Design Guide, is in compliance with AASHTO R 50-09, and utilizes modified layer coefficients that have been properly calibrated and validated for the geogrid reinforcement utilized in the MSL in accordance with this Section.

2.1.2A SUBMITTALS

A. Submit representative geogrid product sample.

B. Submit geogrid product data sheet and certification from the Manufacturer that the geogrid product supplied meets the requirements of sub-part 2.02A of this Section.

C. Submit Manufacturer's installation instructions and general recommendations.

2.1.3A QUALITY ASSURANCE

A. Pre-Construction Conference - Prior to the start of construction of the MSL, the Contractor shall arrange a meeting at the site with the geogrid material supplier and, where applicable, the geogrid installer. The Owner and the Engineer shall be notified at least 3 days in advance of the time of the meeting. A representative of the geogrid supplier shall be available on an "as needed" basis during construction.

2.1.4A DELIVERY, STORAGE, AND HANDLING

A. Storage and Protection

1. Prevent excessive mud, wet concrete, epoxy, or other deleterious materials from coming in contact with and affixing to the geogrid materials.
2. Store at temperatures above -20 degrees F (-29 degrees C).
3. Rolled materials may be laid flat or stood on end.
4. Geogrid materials should not be left directly exposed to sunlight for a period longer than the period recommended by the manufacturer.

2.2A PRODUCTS – OPTION A

2.2.1A MANUFACTURERS

A. An approved source of geogrid is The Tensar Corporation, Morrow, GA or its designated representative. Other suppliers are also acceptable provided that all provisions of this specification with regard to design documentation, product performance validation, and alternate material submittals are met.

2.2.2A MATERIALS

A. Stabilization Geogrid – The geogrid component of the MSL shall be TriAx TX5 or TX7 and shall be integrally formed and produced from a punched sheet of polypropylene, which is then oriented in three substantially equilateral directions. The resulting ribs shall have a high degree of molecular orientation, which continues at least in part through the mass of the integral nodes.

B. The resulting geogrid structure shall have apertures that are triangular in shape, and shall have ribs with a depth-to-width ratio greater than 1.0.

C. The geogrid shall have the nominal characteristics shown in the table below, and shall be certified in writing by the manufacturer to be the product shown on the contract drawings and incorporated in the MSL design by the Engineer:

TX5

Properties	Longitudinal	Diagonal	Transverse	General
Rib pitch, mm (in)	40 (1.60)	40 (1.60)	-	
Mid-rib depth, mm (in)	-	1.3 (0.05)	1.2 (0.05)	
Mid-rib width, mm (in)	-	0.9 (0.04)	1.2 (0.05)	
Rib shape				rectangular
Aperture shape				triangular

TX7

Properties	Longitudinal	Diagonal	Transverse	General
Rib pitch, mm (in)	40 (1.60)	40 (1.60)	-	
Mid-rib depth, mm (in)	-	2.0 (0.08)	1.6 (0.06)	
Mid-rib width, mm (in)	-	1.0 (0.04)	1.3 (0.05)	
Rib shape				rectangular
Aperture shape				triangular

2.3A EXECUTION – OPTION A

2.3.1A EXAMINATION

A. The Contractor shall check the geogrid upon delivery to verify that the proper material has been received. The geogrid shall be inspected by the Contractor to be free of flaws or damage occurring during manufacturing, shipping, or handling.

2.3.2A PREPARATION

A. The subgrade soil shall be prepared as indicated on the construction drawings or as directed by the Engineer.

2.3.3A INSTALLATION

A. The MSL shall be constructed at the proper elevation and alignment as shown on the construction drawings.

B. The geogrid shall be installed in accordance with these plans and specifications and any installation guidelines provided by the manufacturer or as directed by the Engineer.

C. The geogrid may be temporarily secured in place with ties, staples, pins, sand bags or backfill as required by fill properties, fill placement procedures or weather conditions or as directed by the Engineer.

2.3.4A GRANULAR FILL PLACEMENT OVER GEOGRID

A. Granular fill material shall be placed in lifts and compacted as directed under Section XX and Section XX. Granular fill material shall be placed, spread, and compacted in such a manner that minimizes the development of wrinkles in the geogrid and/or movement of the geogrid.

B. A minimum loose fill thickness of 6 inches (150mm) is required prior to operation of tracked vehicles over the geogrid. Turning of tracked vehicles should be kept to a minimum to prevent tracks from displacing the fill and damaging the geogrid. When underlying substrate is trafficable with minimal rutting, rubber-tired equipment may drive directly on the geogrid at slow speeds (less than 5 mph). Sudden braking and sharp turning movements shall be avoided.

2.3.5A INSPECTION

A. The Owner or Owner's representative may randomly inspect geogrid before, during and after (using test pits) installation.

B. Any damaged or defective geogrid (i.e. frayed coating, separated junctions, separated layers, tears, etc.) shall be repaired/replaced in accordance with Section 3.06.

2.3.6A REPAIR

A. Any roll of geogrid damaged before, during, or after installation shall be replaced by the Contractor at no additional cost to the Owner.

B. Proper replacement shall consist of replacing the affected area adding 3ft (1m) of geogrid beyond the limits of the affected area.

2.3.7A PROTECTION

A. Follow the Manufacturer's recommendations regarding protection from exposure to sunlight.

2.1B SYSTEM DESCRIPTION – OPTION B

A. <u>Option B – Chemically Stabilized Layer -</u> This work shall consist of chemical treatment of the aggregate base course to provide improved structural properties of the layer for use in a pavement structure. Chemical treatment of aggregate may include the addition of portland cement, bitumen, similar materials, or combinations thereof to achieve the required strength and/or stiffness for this layer to meet the design parameters.

2.1.1B DESCRIPTION

A. The work covered by this section consists of constructing and curing a chemically treated base composed of aggregate, a chemical stabilizing agent(s), and water, mixed on the roadway and compacted in accordance with these specifications and in conformance to the lines, grades, depths, and typical sections shown on the plans or established by the Engineer.

2.1.2B DESIGN & PERFORMANCE

A. The design of the pavement shall be in accordance with the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures*.

B. The Chemically Stabilized Layer within the pavement structure shall have a thickness of XX inches (XXX mm), or as shown on the contract plans.

C. The design of the pavement shall be based on the following parameters:
   a. Design traffic = 100,000 ESALs
   b. Chemical Stabilized Layer SN = N/A

D. The CSL shall be incorporated into the pavement design by utilizing modified layer coefficients. Modified layer coefficients shall be derived from, and calibrated and validated with, the results of full scale laboratory, field and/or accelerated pavement testing where actual and representative CSLs are tested in representative conditions.

E. Designs based solely on the engineering properties of CSLs derived from laboratory testing of lab-scale CSL specimens (i.e. compressive strength, resilient modulus, or similar) are not sufficient to understand the performance capabilities of a CSL and cannot reliably predict pavement performance. Therefore, all CSL design methodologies utilized must include calibration and validation with results of full scale laboratory, field and/or accelerated pavement testing where actual CLSs are tested in representative conditions.

F. Any submittal for an alternative CSL must be submitted at least 2 weeks in advance of the bid date and must include, at a minimum, the following:

1. A design signed and sealed by a professional engineer registered to practice in the country, state or province in which the project is located.
2. A written statement from the alternative CSL design engineer-of-record that the design is based on the AASHTO 1993 *Pavement Design Guide* and utilizes modified layer coefficient that have been properly calibrated and validated for the CSL in accordance with this Section.

2.2B MATERIALS – OPTION B

A. All materials shall meet the requirements of applicable Sections of this specification as shown below:

1. Portland cement, Section XXX
2. Water, Section XXX
3. Aggregate, Section XXX
4. Lime, Section XXX
5. Bitumen, Section XXX

2.3B EXECUTION – OPTION B

2.3.1B LIMITATIONS

A. Chemically treated base shall not be constructed from November 1 to March 31 inclusive, and shall not be constructed when the air temperature is less than 40 degrees Fahrenheit in the shade, nor when conditions indicate that the temperature may fall below 40 degrees Fahrenheit within 24 hours. No frozen materials shall be incorporated into the mixture and no material shall be placed on frozen subgrade. The base shall be protected from freezing for a period of 7 days after completion. Work shall be performed only during daylight hours unless otherwise provided by the provisions of the traffic control plans. No chemically treated base shall be placed that will not be covered with additional pavement materials by December 1 of the same calendar year.

2.3.2B EQUIPMENT

A. Any combination of machines or equipment that are in good, safe working condition and that will produce results meeting these requirements may be used upon approval of the Engineer. Equipment necessary for proper performance of the work shall be on the project and approved by the Engineer prior to its use in construction operations. The machines and equipment shall be maintained in a satisfactory operating condition at all times during use. Leakage of water, oil, grease, or other objectionable materials shall be corrected promptly or the Engineer may order such equipment removed from the project and replaced with satisfactory equipment.

2.3.3B PREPARATION OF SUBGRADE

A. The subgrade shall be prepared in accordance with the project requirements and approved by the Engineer prior to further construction activities. The subgrade shall be firm and able to support, without displacement, the construction equipment and the compaction operations hereinafter specified. Soft or yielding subgrade shall be corrected and made stable before construction proceeds. The subgrade shall be moistened as needed prior to spreading the base material.

2.3.4B SPREADING AND MIXING

A. Each lift of aggregate shall be placed on the prepared subgrade in a uniform layer. Aggregate shall be spread on the subgrade in advance of the mixing operations only to the extent that processing can be completed within one week. The required quantity of chemical stabilizing agent(s) shall then be applied uniformly on the aggregate in place and immediately blended until the chemical stabilizing agent is uniformly distributed throughout the aggregate. At the time of application of the chemical stabilizing agent, the moisture content of the aggregate shall not exceed optimum moisture. Chemicals shall not be applied on excessively windy days and shall be applied only to such an area that all operations can be completed on the same day during daylight hours.

B. [INSERT ADDITIONAL REQUIREMENTS FOR THE SPREADING AND MIXING OF THE CSL HERE AS NEEDED, INCLUDING MINIMUM REQUIRED CONTENT OF CHEMICAL STABILIZING AGENT(S), WATER APPLICATION PROCEDURES AND RATES, MOISTURE CONTENT OF THE CSL.]

2.3.5B COMPACTION

A. The compacted thickness of any one layer of chemically treated aggregate base shall not exceed 8 inches (200mm) and shall not be less than 4 inches (100mm). Compaction shall be accomplished by the use of approved self-propelled rollers except that a sheep-foot roller shall not be used for more than 2 passes. [INSERT ADDITIONAL COMPACTION REQUIREMENTS HERE THAT ARE APPROPRIATE TO THE TYPE OF CSL SPECIFIED.]

B. Final compaction, including that necessary due to correction of high or low areas, shall be completed within 3 hours. Any CSL mixture that has not been compacted and finished shall not remain undisturbed for more than 30 minutes. When rain causes excessive moisture, the entire section shall be reconstructed. When such reconstruction is necessary, the work of reconstruction and the materials required shall be furnished at no cost to the Owner.

2.3.6B CONSTRUCTION JOINTS

A. At the end of each day's construction, a straight transverse construction joint shall be formed by cutting back into the completed work to form a vertical face. The base for large, wide areas shall be built in a series of parallel lanes of convenient length and width meeting the approval of the Engineer. Straight longitudinal joints shall be formed at the edge of each day's construction by cutting back into the completed work to form a vertical face free of loose or shattered materials. Where traffic considerations require that a longitudinal joint be exposed for an excessive length of time, the Engineer may require that it be covered with a curing seal.

2.3.7B TOLERANCES

A. After final shaping and compacting of the base, the Engineer will check the surface of the base for conformance to the grade and typical section and determine the base thickness. The thickness of the base shall be within a tolerance of plus or minus 1/2 inch (12.5mm) of the base thickness required by the plans. The maximum differential between the established grade and the base within any 100 foot section shall be 1/2 inch (12.5mm).

2.3.8B CURING

A. [INSERT REQUIREMENTS FOR THE CURING OF THE CSL TO MEET THE DESIGN REQUIREMENTS HERE]

2.3.9B TRAFFIC

A. Completed sections of the base may be opened when necessary to lightweight local traffic, provided the base has hardened sufficiently to prevent marring or distorting of the surface, and provided the curing is not impaired. Construction equipment shall not use the base except as necessary to discharge into the spreader during paving operations.

2.3.10B MAINTENANCE

A. The Contractor shall maintain the base in an acceptable condition until final acceptance of the project. Maintenance shall include immediate repair of any defects or damage that may occur. This work shall be performed by the Contractor at no cost to the Owner and shall be repeated as often as may be necessary to keep the base in an acceptable condition. Repairs to the base shall be performed by replacing the base for its full depth rather than by adding a thin layer of chemically stabilized material to the existing layer of base.

2.1C SYSTEM DESCRIPTION – OPTION C

A. Option C – Unbound Aggregate Layer – This work shall consist of furnishing all materials, labor, and equipment for the construction of an aggregate base layer as detailed herein and shown on the contract drawings. The Unbound Aggregate Layer has been designed as an integral part of the pavement structure in order to achieve the required traffic capacity. Any deviation from the original design configuration must be approved by the Engineer, and must demonstrate compliance with all relevant design requirements as determined by the Engineer.

2.1.1C DESIGN & PERFORMANCE

A. The design of the pavement shall be in accordance with the 1993 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures*.

B. The Unbound Aggregate Layer within the pavement structure shall have a thickness of XX inches (XXX mm) or as shown on the contract drawings.

C. The design of the pavement shall be based on the following parameters:
   a. Design traffic = XXXXXX ESALs
   b. Unbound Aggregate Layer SN = XX

2.2C MATERIALS – OPTION C

A. All materials shall meet the requirements of applicable Sections of this specification as shown below:

1. Aggregate, Section XXX

2.3C EXECUTION – OPTION C

2.3.1C PREPARATION

A. The subgrade soil shall be prepared as indicated on the construction drawings or as directed by the Engineer.

2.3.2C INSTALLATION

A. The Unbound Aggregate Layer shall be constructed at the proper elevation and alignment as shown on the construction drawings.

2.3.3C UNBOUND AGGREGATE PLACEMENT

A. Granular fill material shall be placed in lifts and compacted as directed under Section XXX and Section XXX.

3.0 BASIS OF PAYMENT – ALL OPTIONS

3.1 Unit of Measure

The Aggregate Base Layer shall be paid for by the square yard (square meter).
The unit price bid per square yard (square meter) shall include all materials, labor, equipment, storage, private lab testing, sampling, handling, excavation, disposal, tools, removal, placement, hauling, shaping, compacting, surveying, finishing to grade, curing, fees, permits, and proof-rolling, including all appurtenances and incidentals necessary to complete the work. Test rolling and/or proof rolling shall be considered incidental to the contract and will not be measured or paid for separately.

Payment will be made under:

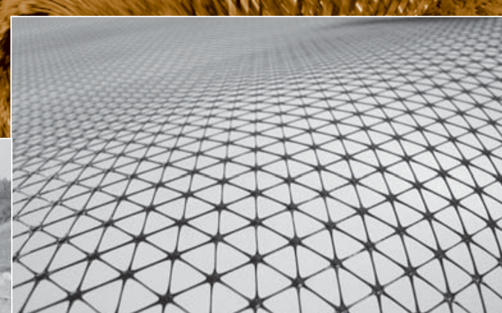
PAY ITEM	PAY UNIT
Stabilized Aggregate Layer	Square Yard (Square Meter)

END OF SECTION

4. APPENDIX D. – INSTALLATION GUIDE

SPECTRA®
ROADWAY IMPROVEMENT SYSTEM

INSTALLATION GUIDE



Tensar®
INTERNATIONAL

The Spectra® System incorporates a mechanically stabilized base or subbase layer that offers a predictable, cost-effective solution.

Tensar® Geogrids

The **Spectra System** owes its strength and durability to **TriAx,®** Tensar's patented reinforcement geogrids. With its unique triangular structure, **Tensar® TriAx® Geogrid** represents an advancement in geogrid technology. Its multi-directional properties leverage the triangular geometry to provide in-plane stiffness through 360°.

Introduction

When weak subgrade, heavy loads, thick fill layers, high structural fill costs, contaminated subgrades or shallow utilities disrupt your construction schedule or budget, the Spectra® Roadway Improvement System can provide an optimal solution. The Spectra System includes mechanically stabilized layers (MSL) utilizing one or more layers of Tensar TriAx Geogrid. The purpose of this Installation Guide is to provide guidance for the installation of the MSL incorporating Tensar TriAx Geogrid.

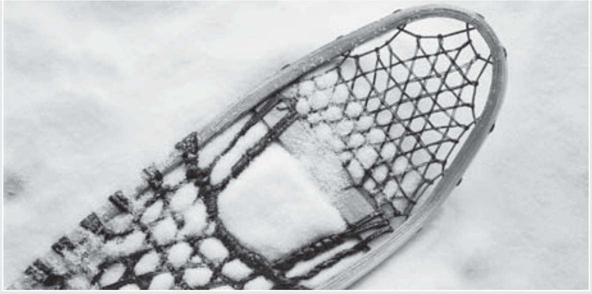
Not only does this system allow access and construction for less than ideal situations, it also offers a predictable engineered solution. This solution relies on Tensar® TriAx® (TX) Geogrids and granular fill acting together to create a stronger composite structure. The mechanically stabilized layer increases the performance of both paved and unpaved road structures.

Tensar TriAx Geogrids have proven their performance and cost-efficiency in thousands of applications. Over soft ground, Tensar TriAx Geogrids improve the soil's effective bearing capacity by distributing applied loads more efficiently, similar to the way a snowshoe supports a man's weight over soft snow. Tensar TriAx Geogrids interlock and stiffen triangular fill materials by confining granular particles within the triangular apertures, thus yielding a stronger component for increased serviceability and durability.

The long-term performance of both paved and unpaved applications are predetermined by ground or foundation support. Proper geogrid installation is also based on subgrade strength. We use California Bearing Ratio (CBR) to quantify this important variable and correlate most measures of soil subgrade support values (such as R-value, SPT data, k-value, M_r, and C_u) to CBR.

Tensar TriAx Geogrids are used to minimize aggregate fill requirements, reduce or eliminate undercut, improve compaction, serve as a construction platform and extend service life. These features depend upon the proper installation procedures presented in this guide.*

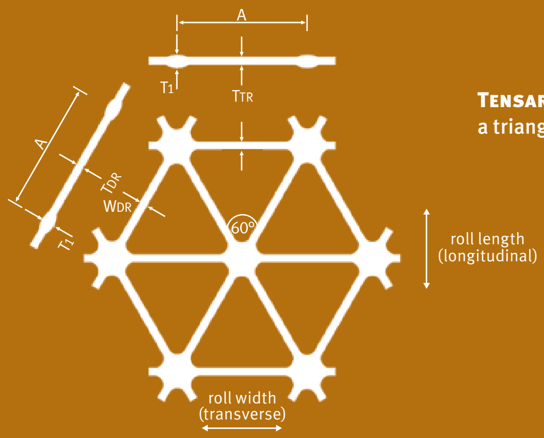
*This guide cannot account for every possible construction scenario, but it does cover most applications of the Spectra System. If you have questions regarding a specific project, call 800-TENSAR-1 or visit www.tensar-international.com.



The Snowshoe Effect – Tensar TriAx Geogrids distribute heavy loads over soft soils just like a snowshoe supports the weight of a man over soft snow.

Spectra® System Components

COMPONENT	FUNCTION
Tensar TriAx Geogrids	Stiff geosynthetic reinforcement
Design	Roadway sections developed using the latest design technology
Site Assistance	Expert Tensar personnel available to visit the project site to ensure an expedited installation



Tensar® TriAx® Geogrids have a triangular aperture structure.

1. Getting Started

- When placing an order, communicate all pertinent project and/or application criteria, including certification requirements, if any, to your Tensar International Corporation (TIC) representative. It is normally advisable to schedule a pre-construction meeting with this representative and any other appropriate parties at this time.
- Upon delivery, check the Tensar® TriAx® Geogrid roll labels to verify that the intended product has been received. For instance, TX5 and TX7 Geogrids have a similar appearance, but different structural characteristics so their distinction is important. Inspect the geogrid to ensure it is free of any flaws or damage that may have occurred during shipping or handling. If variable roll widths are supplied, please confirm that the correct quantities have been delivered. Tensar TriAx Geogrid rolls are assigned distinct nomenclature to distinguish the roll width and length.*
- Store Tensar TriAx Geogrids in a manner that prevents excessive mud, wet concrete, epoxy or other deleterious materials from coming in contact with and affixing to the geogrid. Store geogrids above –20˚F (–29˚C) and avoid handling below 14˚F (–10˚C). Please contact TIC if project conditions require storing and handling beyond these recommended limits. Tensar TriAx Geogrids may be stored uncovered for up to six (6) months in direct exposure to sunlight without any loss of certifiable structural properties (contact TIC if longer exposure is anticipated). The geogrids may be stored vertically (rolls stood on end) or horizontally in stacks not exceeding four rolls high (Image 1).
- Anticipate potential issues and resolve them with TIC prior to construction. To contact the local TIC representative for your area, call 800-TENSAR-1.

Tensar® TriAx® Geogrid

Product	Roll Width	Roll Length
Tensar TriAx TX5-475	13.1 ft (4 m)	246 ft (75 m)
Tensar TriAx TX7-450	13.1 ft (4 m)	164 ft (50 m)

*Additional roll characteristics can be found on page 9 of this guide under “Tensar TriAx Roll Characteristics.”

Image 1 Storing the Tensar TriAx Geogrid rolls (horizontally).

Image 2 Rolling out Tensar® TriAx® Geogrid.

2. Site Preparation

- Clear, grub and excavate (if necessary) to the design subgrade elevation, stripping topsoil, deleterious debris and unsuitable material from the site. For very soft soils (CBR < 0.5), it may be beneficial to minimize subgrade disturbance and leave root mats in place. Cut stumps and other projecting vegetation as close and even to the ground surface as practical. For moderately competent soils (CBR > 2), it may be prudent to lightly proof roll the subgrade to locate unsuitable materials. When possible, backdrag to smooth out any ruts.
- Smooth grade and compact the soils using appropriate compaction equipment. Swampland, peat, muskeg or marshes may be difficult to smooth grade and/or compact. In these situations, create a surface that is as uniformly smooth as possible. Grade or crown the surface for positive drainage away from the construction zone.

Note: Routine construction procedures are normally recommended for site preparation. Special measures are rarely required to accommodate Tensar TriAx Geogrids.

- Place the rolls of Tensar® TriAx® Geogrid* in position, cut the roll tape and manually unroll the material over the prepared surface (Image 2). In unpaved applications, this surface will always be the subgrade. In paved applications, it may be the subgrade, the granular subbase or an elevation (ex., mid-depth) within the aggregate base course.
- Fine grained, non-cohesive soils such as silts present unique challenges, especially with the presence of excessive moisture. TIC recommends that a Tensar representative be contacted so that site conditions can be analyzed to ensure the geogrid performance is optimized.

*Tensar International Corporation manufactures several different types of geogrid. Selection and optimization depends on structural performance requirements, subgrade and fill parameters, economic considerations and local availability.

Summary of Tensar® TriAx® Geogrid Installation Parameters

Subgrade Strength	Clear All Vegetation?	Geogrid Orientation[3]	Geogrid Overlap[4]	Nylon Zip Ties?[1, 2]	Direct Traffic?[5]	Geotextile?[6]
CBR ≤ 0.5	N	T or L	3 ft	Y	N	Analysis Req'd
0.5 ≤ CBR ≤ 2	Usually	L	2–3 ft	N	N	Analysis Req'd
2 ≤ CBR ≤ 4	Y	L	1–2 ft	N	Limited	Analysis Req'd
4 ≤ CBR	Y	L	1 ft	N	N	N

Notes:
1. Summary is a generalized presentation; see text for specifics.
2. Y = Yes, normally required; N = No, not normally required.
3. Geogrid Orientation (roll axis in relation to traffic): T = Transverse, L = Longitudinal.
4. General Geogrid Overlap Rule: Overlap = 3 ft for CBR ≤ 1; Overlap = 1 ft for CBR ≥ 4; interpolate between.
5. Direct Traffic pertains only to conventional rubber-tired equipment.
6. Analysis Required = Geotextile required only if filtration criteria is not met by aggregate fill.

Table 1

Overlapping Tensar® TriAx® Geogrid in the field is quick and easy.

3. Placing and Overlapping Geogrid

- Unroll the geogrid in the direction of travel so that the long axis of the roll is parallel with channelized traffic patterns. For very soft subgrades (CBR ‹ 0.5), unrolling geogrid transversely or perpendicular to the roadway embankment alignment, may be preferred, particularly if lateral spreading and separation of overlaps is a concern (Table 1).
- Overlap adjacent rolls along their sides and ends in accordance with Table 1.
- Overlap (“shingle”) geogrids in the direction that the fill will be spread (Image 3) to avoid “peeling” of geogrid at overlaps by the advancing fill. To expedite the shingling process, consider placing rolls at the far end of the coverage area first, and work toward the near end from where the fill will be advanced. Weaker subgrades that are easily rutted with conventional construction traffic will require an end-dumping operation. Please refer to page 7 “Dumping and Spreading Aggregate Fill” for more information.
- Adjacent geogrid rolls are normally not connected to one another, particularly if fill is placed and spread as described herein (Table 1). A notable exception is over very soft subgrades (CBR ‹ 0.5) where nylon cable ties (or “zip ties”) can be effective in helping maintain overlap dimensions. These ties are not considered structural connections, but rather construction aids. In most applications their use is not required.
- Cut and overlap the geogrid to accommodate curves (Image 4). Cutting may be done with sharp shears (Image 5), a knife-like implement or handheld power (i.e., “cutoff”) saws. Cut the geogrid to conform to manhole covers and other immovable protrusions such as vertical utilities.
- In some cases, especially on cooler days, Tensar® TriAx® Geogrid will exhibit “roll memory” where a few feet may roll back upon cutting or reaching the end of the roll. It is recommended that the installer take appropriate measures to ensure that the product lies flat during fill placement. This can be easily achieved by using sod staples, zip ties or simply adding a shovelful of fill to weigh down the product.
- **Safety Note**: The use of safety glasses and gloves is highly recommended when installing Tensar TriAx Geogrids.

Image 3 Tensar TriAx Geogrid should overlap in the direction of advancing fill.

Image 4 Placing Tensar TriAx Geogrid to accommodate curves.

Image 5 Cutting Tensar TriAx Geogrid is easily achieved.

4. Tensioning and Anchoring

Tensar® TriAx® Geogrids may be anchored in place to aid in maintaining product overlaps and alignment over the coverage area.

- Before fully unrolling the geogrid, anchor the beginning of the roll, in the center and at the corners, to the underlying surface.
- Anchor the geogrid with small piles of aggregate fill (Image 6), if necessary. Alternatively, sod staples or washers and pins may also be used by driving them into the subsoil through the apertures of the geogrid. This measure is rarely required unless a significant crown or sloping of the subgrade requires some mechanical anchoring to prevent lateral sliding of the product during fill placement.
- Unroll the geogrid. Align and pull it taut to remove wrinkles and laydown slack with hand tension, then secure in place as necessary. Because of the unique manufacturing process and roll sizes of Tensar TriAx Geogrid, maneuvering an unrolled sheet of geogrid is easily achieved. **Gloves should be worn while handling Tensar TriAx Geogrids.**
- Additional shoveled piles of aggregate fill may be required to hold the geogrid in place prior to placement of the aggregate fill along overlaps and the ends of rolls.
- When constructing over very soft soils (CBR < 1.0), it is critically important to maintain overlaps during placement of the fill material. The use of nylon zip ties placed every 5–10 ft is optional to maintain the overlap width recommended in Table 1.

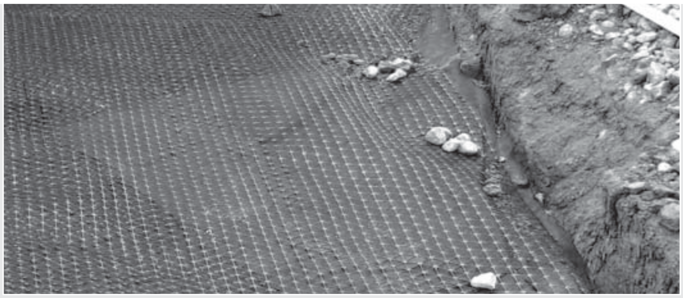


Image 6 Tensar TriAx Geogrid anchored with small piles of aggregate.

5. Dumping and Spreading Aggregate Fill

- Generally, at least 6 in. of compacted aggregate fill is required for the initial lift thickness over a Tensar® TriAx® Geogrid. However, for very soft conditions, a significantly thicker fill layer will be required to prevent excessive rutting and/or bearing capacity failure of the underlying subgrade soils.
- Over relatively competent subgrades (CBR › 4, see Table 1), aggregate fill may be dumped directly onto the geogrid. **Standard, highway-legal, rubber-tired trucks (end dumps and belly dumps) may drive over the geogrid at very slow speeds (less than 5 mph) and dump aggregate fill as they advance, provided this construction traffic will not cause significant rutting upon bare subgrade. Turns and sudden starts and stops should be avoided.**
- Over softer subgrades, back the trucks up and dump fill from the edge of the previously placed material (Image 7). For very soft subgrades (CBR ‹ 0.5), extreme caution should be taken to avoid overstressing the subgrade soil both during and after fill placement. Please contact a Tensar representative at 800-TENSAR-1 for guidance with constructing over very soft subgrade soils (CBR ‹ 0.5).
- Do not drive tracked equipment directly on a Tensar TriAx Geogrid. Ensure at least 6 in. of compacted aggregate fill (or the required minimum design fill thickness) is spread between the geogrid and any tracked equipment (Image 8).
- Over softer subgrades (CBR ‹ 1.5), a lightweight, low ground pressure (LGP) dozer is recommended to evenly push out the initial lift of fill over the exposed geogrid.
- Care should be taken not to catch the dozer blade or other equipment on the geogrid. The dozer blade should be raised gradually as each lift is pushed out over the geogrid. The desired effect is fill that cascades onto the geogrid, rather than being pushed into it.
- When building over a soft subgrade, it is desirable to work from stronger to weaker areas.
- Be aware of geogrid overlaps and advance the aggregate fill with the shingle pattern.

Note: When aggregate fill is spread by pushing it over the geogrid with heavy equipment, such as bulldozers, the shoving action may create a "wave" in the sheet of geogrid ahead of the advancing fill. Shoveled fill can trap this wave and force the geogrid up into the aggregate layer where it can be damaged by the spreading equipment. Pulling the geogrid taut will mitigate laydown slack, thereby removing "waving." If significant waving occurs, the shoveled material should be removed to allow the waves to dissipate at the ends and edges of the roll.

Image 7 End dumping aggregate fill on top of Tensar TriAx Geogrid over soft subgrade.

Image 8 Spreading aggregate fill over Tensar TriAx Geogrid.

Image 10 Compacting the aggregate fill.

6. Compacting

- Standard compaction methods may be used unless the soils are very soft. In these cases, static instead of vibratory compaction is prudent, particularly over fine-grained, non-cohesive soils such as silt. Compaction is then achieved using a light roller. Keeping the moisture content of the fill material near optimum will make compaction more efficient. Water spray is most effective with sand fill (see Image 9). For construction over very soft soils, compaction requirements are normally reduced for the initial lift as the primary intent of the initial lift is to achieve a suitable working surface.
- If rutting or severe pumping occurs under truck or dozer traffic, fill should be added immediately to strengthen the section. Saturated silty subgrades are particularly prone to pumping. In some cases, it may be prudent to cease operations for a period of time, allowing pore pressures to dissipate and the subgrade to stabilize. Otherwise, de-watering measures such as "bleeder ditches" should be considered to reduce the moisture content of the uppermost silty subgrade layer. Please contact a Tensar representative for more information.
- Compact aggregate fill to project specifications, after it has been graded smooth and before it is subject to accumulated traffic (Image 10). Inadequate compaction will result in surface rutting under wheel loads. Rutting reduces the total effective thickness of the fill and increases stress on the subgrade.*
- If the aggregate fill thickness is insufficient to support imposed load(s) when constructing over soft soil, excessive subgrade and surface rutting will result. Measures should be taken to ensure the proper thickness of granular fill is placed atop the geogrid to maximize support and minimize movement at the surface.

*Note: Compaction equipment and methods should be appropriate for the type of fill being used, its thickness and the underlying subgrade conditions.

Image 9 Moistening the fill before compaction.

Tensar® TriAx® Geogrid Roll Characteristics								
	Roll Width		Roll Length		Roll Area		Roll Weight	
Product	(m)	(ft)	(m)	(ft)	(m^2)	(SY)	(kg)	(lbs)
Tensar TriAx TX5-475	4	13.1	75	246	300	358.5	66.4	143
Tensar TriAx TX7-450	4	13.1	50	164	200	239	58.2	128

7. Special Considerations

Make Repairs

- If Tensar® TriAx® Geogrids become damaged during or after installation, repair them by patching the area with the following measures:
  1. Remove fill from the surface of the damaged geogrid and clear a 3-ft area around the damage.
  2. The geogrid patch should cover the damaged area and extend 3 ft beyond it in all directions.

Surface Rutting

- If deep rutting occurs beneath truck wheels, do not grade out the ruts. Rutting is normally indicative of fill that is too thin, too wet or inadequately compacted. Grading out the rut will reduce aggregate fill thickness between the wheel paths and may lead to geogrid exposure.
- Fill in the ruts with additional specified aggregate fill and compact. This places extra fill where it's needed and may prevent further rutting under channelized traffic.
- Crown the fill during the grading process to ensure rainfall runoff and to prevent fill saturation.

Cold Weather

- At sub-freezing temperatures, the polymer in a Tensar TriAx Geogrid becomes less resistant to impact and can be fractured by applying a dynamic force (i.e., striking with a hammer). Other aspects of dynamic loading associated with very cold temperatures should be avoided. Tensar Geogrids may be installed in extremely cold climates as long as proper storage and placement procedures are employed. For more information regarding the installation of geogrids in cold climates, please consult a Tensar representative at 800-TENSAR-1.

Aggregate Fill Considerations

- The preferred (not required) fill gradation for roadway applications is well-graded crushed aggregate fill with a maximum particle size of 1½ in. and less than 10% fines (passing #200 sieve). The gradation ranges listed below are recommended for the enhanced load distribution and positive drainage of flexible pavement applications where granular base courses are typically utilized. For unpaved applications, most clean granular fills, including sands, are acceptable.

Preferred Fill Gradation	
Size	% Passing
1½ in.	100
¾ in.	50–100
#4	25–50
#40	10–20
#100	5–15
#200	less than 10

Image 12 A backhoe excavation through a Tensar TriAx Geogrid.

Excavating Through Tensar® TriAx® Geogrid

When confined beneath and within compacted fill, the geogrid should pose no significant challenges to post-construction activities like utility trenching or driving/auguring supports for rails, signs or standards. Conventional excavation equipment will shear directly through the geogrid leaving a clean cut as shown in Image 12

- Tensar® TriAx® Geogrids will structurally enhance coarser or finer fill gradations, as long as the aggregate fill is compacted and placed at, or just below, optimum moisture content. For coarser fill, a graded filter analysis is recommended to guard against potential contamination from the underlying subgrade (see Table 1 on pg. 4). If the aggregate fill does not meet the requirement(s) of a graded filter over soft and saturated clays and silts it is recommended that a sand filter layer be placed at a minimum depth of 6 in. on top of the geogrid layer. The sand fill thickness may need to be increased in the event the design fill thickness requires a thicker initial lift.
- The use of uniformly sized coarse granular fill is not recommended as it does not compact well and may rut under repeated wheel loading, despite the improved stability brought about by Tensar TriAx Geogrids.
- The moisture content of the fill should not exceed optimum. Wet granular fill is not easy to compact and may perform poorly under construction equipment wheel loading. The use of poor quality and/or overly wet fill material that is difficult to prepare and compact over a firm condition, even with Tensar TriAx Geogrid, is not recommended.

Preferred Equipment

- Soft Ground – the preferred equipment imposes low contact pressure on the ground surface. This may be done with smaller machinery and/or low ground pressure (LGP) vehicle. Equipment that concentrates heavy loads over a relatively small contact area such as front-end loaders, are not recommended. In all soft ground cases, the fill must be sufficiently thick to avoid overstressing the underlying soils and Tensar TriAx Geogrid.
- Firm Ground – the preferred equipment maximizes productivity for specific construction requirements. Over competent ground, geogrids can be trafficked directly by rubber-tired equipment, making hauling equipment (i.e., dump trucks) and spreading equipment (i.e., motor graders) ideal as shown in Image 11. Spreader boxes are not recommended – wrinkling in the geogrid between the screed and wheels of the box and dump trucks can cause slack to become trapped, raising the geogrid up into the aggregate layer.

Image 11 Tensar TriAx Geogrid can be trafficked directly by rubber-tired equipment.

8. SpectraPave4-Pro™ Software for Paved & Unpaved Applications

Tensar International Corporation breaks new ground with the 2010 release of our industry-leading SpectraPave4-Pro™ Software. This design aid allows the user to accurately predict the performance of geogrid reinforced and unreinforced roads with both paved and unpaved surfaces. The software offers application-specific modules for:

- Unpaved roads
- Paved roads
- Cost Analyses – Initial and Life Cycle

Unpaved Applications Module

Based on the Giroud-Han design methodology, the unpaved applications module incorporates an existing design method, which supports the use of certain geosynthetics, to reduce aggregate thickness requirements and improve the subgrade performance. It indicates the required thickness for unreinforced aggregate fill layers and aggregate fill layers reinforced with Tensar® TriAx® Geogrids.

Paved Applications Module

The SpectraPave4-Pro software includes a module for the design of Spectra System Solutions in paved road applications. This module incorporates the design methodology prescribed by AASHTO in their Pavement Design Guide (1993) and also their Interim Standard PP46-01 (2003). Tensar TriAx Geogrids can be used in an AASHTO design to extend the design life of a flexible pavement and/or reduce the thickness of the pavement layers.

Cost Analysis Tools

The cost analysis tools provide total in-place costs (and savings) for each design option. The results can be represented in dollars per unit area or as a lump sum giving you the flexibility to predict performance and economic benefits for a range of design scenarios. Additionally, the SpectraPave4-Pro software offers the flexibility to evaluate the long-term benefits of Tensar TriAx Geogrids for paved applications using the life cycle cost analysis tool.

SpectraPave-Pro software enables engineers to design a Spectra® System Solution for paved and unpaved roads. In early 2010, the software will be available free of charge following the completion of a short training module. To apply for training and your free software, visit us online at www.tensarcorp.com or call 800-TENSAR-1.

Tensar INTERNATIONAL

A tensar Company

Tensar International Corporation
5883 Glenridge Drive, Suite 200
Atlanta, Georgia 30328

800-TENSAR-1
www.tensar-international.com

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