

PAVEMENT OPTIMIZATION

OVERVIEW



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Paved Roads and the Need for Innovation

Conventional construction practices are presenting new challenges to pavement engineers, contractors and owners due to the availability of material and the volatility of their costs. Construction budgets are under constant scrutiny to deliver the highest quality end product for the least amount of money. Indeed, the practice of implementing a “typical pavement section” is costing many owners both time and money due to a number of factors:

- ▶ Asphalt and crushed aggregate pricing volatility
- ▶ Reduced construction and maintenance budgets
- ▶ Compromised pavement life spans due to increased trafficking or insufficient pavement structure

These factors have decision makers questioning performance estimates and the conventional strategies they once relied upon to evaluate projects and set priorities.

A growing number of transportation professionals are considering designs that incorporate Tensar® International Corporation's TriAx® Geogrid.

TriAx, the groundbreaking triangular stabilization geogrid, is one of the industry's leading solutions for creating mechanically stabilized pavement structures.

A BREAKTHROUGH TECHNOLOGY

In combination with Tensar's engineering and design services, cost-analysis tools and site assistance, TriAx Geogrid provides a simple, reliable and affordable solution for constructing flexible pavements that deliver both reduced construction cost and long-term value.

TriAx offers a proven performance benefit for paved roads by:

- ▶ Reducing pavement component thickness (asphalt, aggregate base and granular subbase)
- ▶ Simplifying construction
- ▶ Lowering long-term maintenance costs

TriAx Geogrid enables you to create durable and cost-efficient engineered structures through the product's unique structure and performance properties.



Reduce Construction Costs and Long-Term Maintenance Needs

COST-EFFECTIVE PAVEMENT DESIGN

Tensar TriAx Geogrid is supported by years of laboratory research, full-scale testing and practical experience in the field. Numerous studies and installations worldwide have proven that the mechanically stabilized base layer provides increased pavement support and load-spreading capabilities. These characteristics deliver two major benefits for pavement designers:

- **Lower Initial Costs:** Full-scale research indicates that a significant reduction in pavement component thickness can be achieved by incorporating TriAx Geogrid:
 - Reduction of asphalt layer: 15-30%
 - Reduction of aggregate layer: 25-50%

Cost savings are realized through the reduction of raw material usage and hauling and placement charges.

(See construction cost savings example on page 15.)

- **Reduced Life Cycle Costs:** Through the unique properties of TriAx Geogrids, engineers, contractors and owners can utilize a solution that extends the service life of a pavement structure, sometimes by as much as 500%. An extended service life reduces maintenance and extends rehabilitation intervals, yielding significant life cycle cost savings over conventional solutions. (See life cycle cost benefit example on page 16.)

These performance improvements have been demonstrated through the monitoring of full-scale pavements constructed on a range of subgrades (CBR values) and with various asphalt thicknesses. The benefits provided by TriAx Geogrid are valid for most pavement types, from low-volume, light-duty rural roads and parking lots to high-volume highways and heavy-duty industrial pavements.



*Inadequate pavement structure as depicted by **A)** alligator cracking, **B)** block cracking and **C)** spalling due to excess moisture within the structure.*



Just as the pool rack confines these billiard balls, Tensar® TriAx Geogrid confines aggregate particles above, within and below the plane of stabilization.

How Tensar TriAx Geogrid Works

Flexible pavement structures often fail prematurely because of progressive lateral and vertical displacement and a weakening of the aggregate base course. Additionally, asphalt layers develop fatigue cracking with repeated traffic loads and thermal cycling. These factors contribute to the development of rutting and cracks that propagate through the asphalt cement concrete (ACC) layer.

If the subgrade is relatively firm, a Tensar TriAx Geogrid layer is designed to confine the aggregate base course particles. This confinement maintains the structural capacity and improves the performance of the pavement system. If the subgrade is weak, an additional layer of aggregate and TriAx can be used to strengthen it before placing the geogrid stabilized base layer.

LATERAL RESTRAINT IS THE KEY TO AGGREGATE STIFFENING

The U.S. Army Corps of Engineers reported in an engineering technical letter¹ that a geogrid's unique structure provides a high degree of in-plane stiffness through a mechanism known as lateral restraint.

Considered to be the primary reinforcement mechanism of the three mechanisms defined within the Corps' document, lateral restraint is the ability to confine aggregate particles within the plane of the geogrid (see Figure 1). As granular base courses are stress-dependent materials, the confinement offered by stiff, properly designed geogrids increases the modulus of the base material. This stiffening effect occurs both above and below the geogrid when it is installed within a granular fill layer. This results in a modulus increase for the entire stabilized layer.

In thinner pavement structures, a reduction in vertical strain takes place at the top of the subgrade, whereas in thicker pavements, the strain at the asphalt-aggregate interface is significantly reduced. Through the highly efficient lateral confinement mechanism unique to Tensar TriAx Geogrid, thickness is optimized for both light-duty and heavy-duty flexible pavement sections. Refer to Figure 2 for an illustration of this key performance mechanism.



FIGURE 1 The lateral confinement of aggregate reinforcement with Tensar TriAx Geogrid is shown through the box of rocks demonstration.

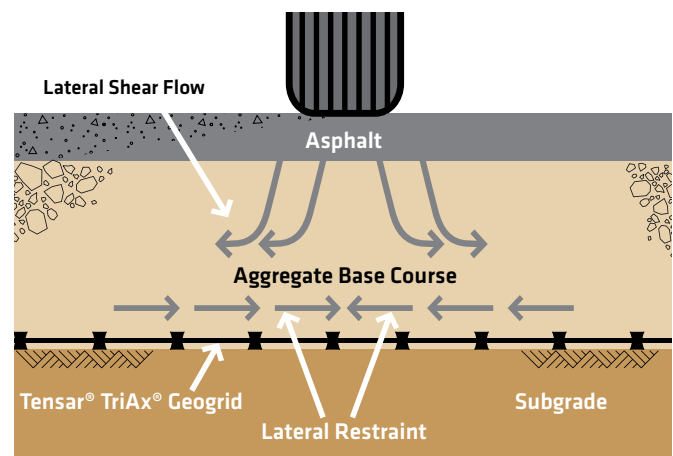
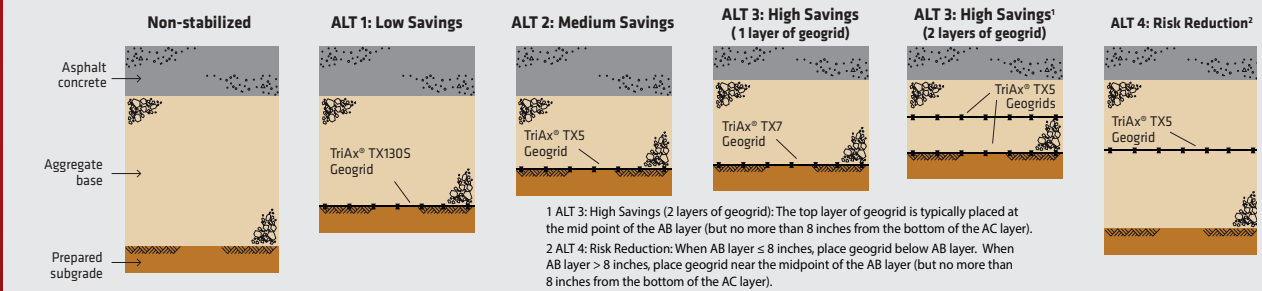


FIGURE 2 Lateral confinement mechanism provided by TriAx Geogrid within a flexible pavement section.

Typical Sections: Flexible Pavement Optimization



BEARING CAPACITY IMPROVEMENT – THE SNOWSHOE EFFECT

Typically associated with geogrid usage over soft subgrades in unpaved applications, improved bearing capacity results from a change in the critical failure mode of the subgrade from localized shear, generally characterized as a deep rutting failure, to a general bearing capacity failure. The result is an improved effective bearing capacity of the subgrade resulting from pressure dissipation at the geogrid-subgrade interface (Figure 3). Generally, this mechanism applies to unpaved applications where stabilization is required to yield a stable working surface. However, it also applies to pavement structures, particularly flexible pavements stabilized with a geogrid at the aggregate-subgrade interface.

Fatigue is typically associated with the displacement of asphalt and aggregate near the surface of a pavement. In contrast, rutting is almost always a result of subgrade soil movement while the structure is in service. As such, bearing capacity improvement, also known as the “snowshoe effect” (Figure 4),

becomes an important mechanism when the subgrade support effectively controls the life span of the pavement structure in relatively thin pavements founded on softer soils.

UNIQUE PROPERTIES AND MECHANISMS ASSOCIATED WITH TENSAR® TRIAX® GEOGRIDS

TriAx Geogrids were developed with a specific purpose in mind: providing significant performance and cost saving benefits relative to all geogrids currently on the market. For a biaxial geogrid, there is high stiffness in the two orthogonal directions but significantly lower stiffness in between. By contrast, the unique triangular apertures of the Tensar TriAx Geogrid ensure that high tensile stiffness is maintained in all directions. Research demonstrates that significant radial stresses occur under moving wheel loads. Hence it is not surprising that a Tensar TriAx Geogrid significantly outperforms a Tensar Biaxial Geogrid in side-by-side pavement trials.

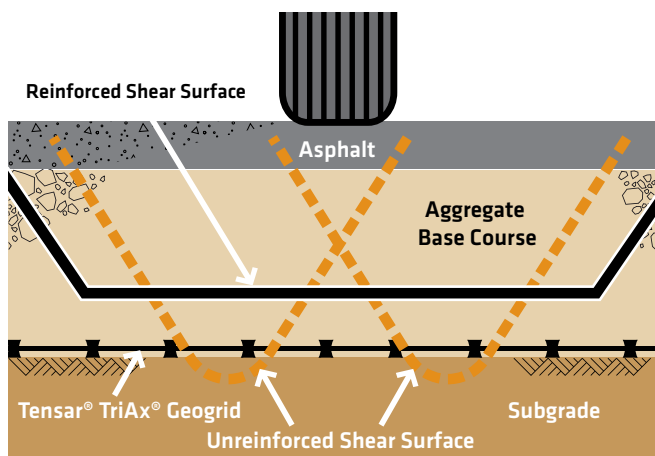


FIGURE 3 Bearing capacity improvement mechanism shown through the inclusion of Tensar TriAx Geogrid at the aggregate base course-subgrade interface.



FIGURE 4 As a snowshoe distributes load over soft snow, Tensar TriAx Geogrid confines aggregate to better distribute in-service loads over soft subgrades.

➤ Tensor TriAx Geogrid extends the life of a roadway through the introduction of a mechanically stabilized layer (MSL) within the pavement structure.



Paved Solutions – Tensor TriAx Geogrid Features

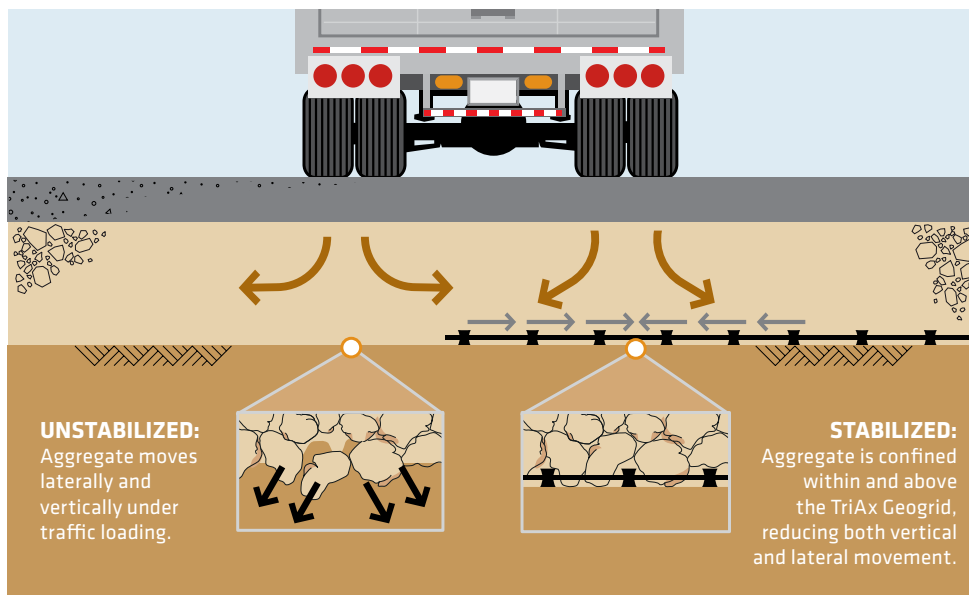
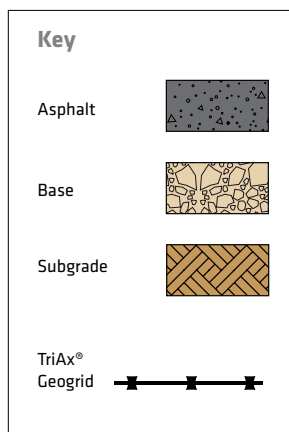
Flexible pavement systems often fail prematurely due to progressive lateral displacement and weakening of the aggregate base course. Moreover, sections with insufficient foundation support will strain gradually due to channelized traffic while the pavement is in service. This results in both rutting and asphalt fatigue, which leads to eventual cracking of the pavement surface. TriAx Geogrid provides a mechanically stabilized layer (MSL) within either the aggregate base or granular subbase, which maintains structural capacity and improves the long-term performance of the pavement system.

In flexible pavement structures, Tensor TriAx Geogrids are traditionally used to stabilize the aggregate base course layer immediately below the asphalt cement concrete. However, where weak subgrades are encountered, it may be appropriate to include an additional granular layer in order to provide a stable working surface prior to constructing the main pavement structure. Under these circumstances, a second layer of Tensor TriAx Geogrid may be required within this lower unbound aggregate layer.

REDUCE COMPONENT THICKNESS

Full-scale research and trials have shown that for a specific set of trafficking conditions, TriAx Geogrid can reduce the aggregate base or subbase thickness by as much as 50%.

Historically, geogrid stabilization was thought to offer the ability to optimize the thickness of granular layers only in flexible pavement applications. However, recent full-scale research has shown that, because of TriAx Geogrid's ability to create enhanced stiffness of the underlying mechanically stabilized aggregate base course, a reduction in the required thickness of the overlying asphalt cement concrete may also be realized. Based on the data currently available, for typical pavement structures, the asphalt thickness can be reduced up to 30%.





INCREASE PAVEMENT LIFE

When quantifying extension of pavement life through decreased surface rutting, it is necessary to consider a relative measurement of pavement distress. The American Association of State Highway and Transportation Officials (AASHTO)² defines this parameter as the traffic benefit ratio (TBR). This is the ratio of cycles-to-failure in a geogrid-stabilized pavement section compared to a stabilized section of the same thickness. Independent, full-scale testing conducted by a number of research entities indicate that TBR can vary significantly depending upon pavement thickness, subgrade support and the type of geogrid stabilization used.

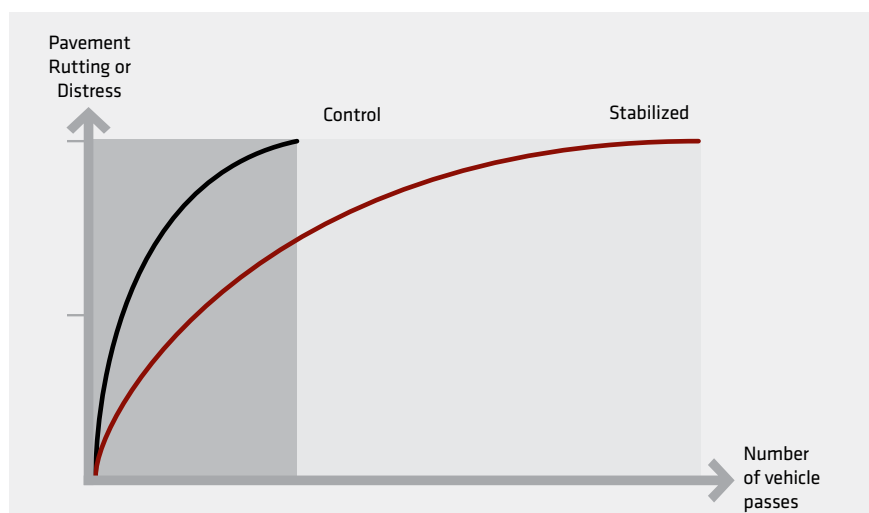
Further details on how to quantify the benefits of using geogrid stabilization in pavement structures is provided by AASHTO³. Within this document it is stated that test section data is required in order to quantify the performance benefit (TBR value) attributable for a specific geogrid product. Extensive full-scale laboratory and field testing has been undertaken on the use of Tensar Geogrids in pavement applications over the last 25 years. As such, the pavement designer can be assured of the accurate quantification of the performance benefits attributable to Tensar Geogrid products.

LONG-TERM AGGREGATE STRENGTH LEADS TO LESS ASPHALT MAINTENANCE

In conventional pavement structures, where the unbound aggregate layer (base course) is generally subjected to “strain softening” (i.e., under repeated load), this layer starts to break down and its stiffness is reduced. Under these circumstances, the level of support provided to overlying pavement layer(s) is also reduced and commonly leads to additional lateral stresses and strains being generated at the bottom of the asphalt.

Instrumentation of full-scale, geogrid-stabilized test sections has demonstrated that not only does TriAx Geogrid increase the stiffness of the aggregate layer, but the enhanced stiffness is also retained for the design life of the pavement structure. This concept is sometimes referred to as “the generation of residual stress within the pavement structure.” The result of this from a pavement owner’s perspective is longer-lasting pavements and lower maintenance costs.

The use of geogrid technology is not just confined to relatively light-duty pavement structures. Mechanically stabilized layers can also be used to provide the same benefits in thicker, heavy-duty pavement structures where the asphalt cement concrete exceeds six inches.



Extension of pavement life with Tensar TriAx Geogrid



Rutting accumulation at the surface and the subgrade were used to compare geogrid performance.

Research: Relevant Proof

Tensar TriAx Geogrid has a long history of use by the Federal Highway Administration (FHWA), state DOTs, county and municipal agencies as well as private owners and developers. It has consistently demonstrated its economic and structural value for both paved and unpaved applications. Many of these same entities have invested in testing to quantify the value associated with geogrid stabilization in pavement applications. As budgets for construction projects are stretched year after year due to increased material costs and dwindling revenues, both public agencies and private developers seek means to make their pavement investment go further and last longer. To this end, the cost benefits of TriAx Geogrid must be substantiated through relevant proof such as research and practical experience.

DOES TENSAR TRIAX GEOGRID OUTPERFORM TENSAR BIAXIAL GEOGRID?

Yes. In order to fully appreciate the potential value of Tensar TriAx Geogrid for paved applications, Tensar made a significant investment in research during the development

phase of this new technology. Tensar's Product Development Team was challenged to produce a technology that would be more cost-efficient to the end user and perform better than the product that set the bar for geogrid performance in paved and unpaved applications for more than 25 years, Tensar BX Geogrid. A series of research projects was performed to both quantify and compare the features and benefits of old and new technologies:

- ▶ Discrete Element Method (DEM) computer modeling
- ▶ Static plate load testing to measure bearing capacity improvement potential
- ▶ Small-scale rolling wheel over unpaved surfaces
- ▶ Full-scale rolling wheel over paved and unpaved surfaces
- ▶ Triaxial cell testing to monitor aggregate stiffness enhancement and retention



Trafficking of Tensar BX Geogrid



Trafficking of Tensar TriAx Geogrid

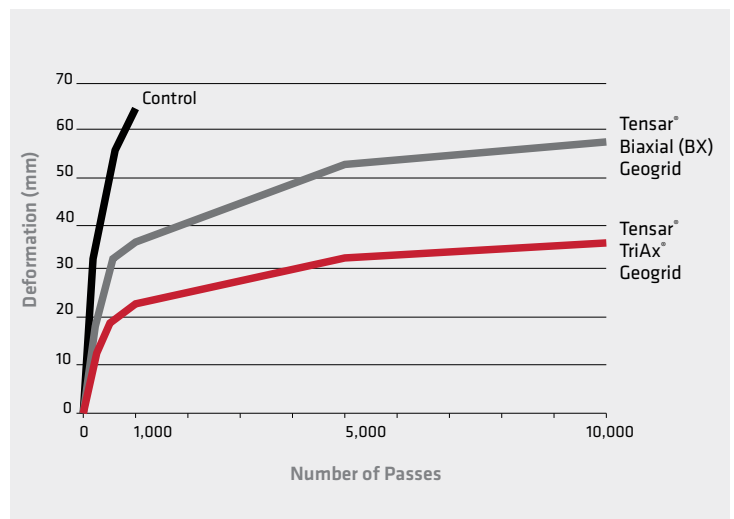


Subgrade rutting with Tensar BX Geogrid

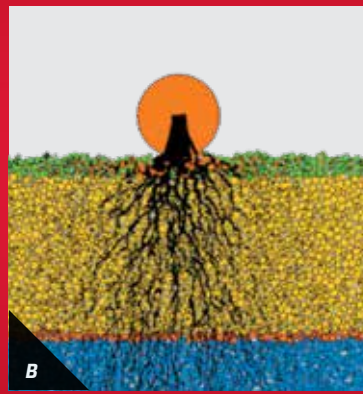


Subgrade rutting with Tensar TriAx Geogrid

Testing using a small-scale trafficking device to compare the performance of Tensar TriAx and Tensar BX Geogrids.



Small-scale rolling wheel tests offered preliminary proof that TriAx Geogrid outperforms Tensar Biaxial Geogrid.



A) *Tensor TriAx Geogrid interlocks with the aggregate base course, yielding a mechanically stabilized layer (MSL).*

B) *This DEM rolling wheel model indicates stress transfer from an imposed load on an asphalt surface pavement section.*

The research showed that the unique aperture geometry and multi-axial confinement potential of Tensor TriAx Geogrid offers superior performance at an even greater value compared to Tensor BX Geogrid for paved and unpaved applications.

GROUNDBREAKING COMPUTER MODELING

Tensor has long supported defining performance characterization of our products and systems through research. These investments have led to the development of innovative products such as Tensor TriAx Geogrid and new methods for predicting performance such as the Tensor Mechanistic-Empirical (M-E) Pavement Design Method. While developing the Tensor M-E method, our research team used the Discrete Element Method (DEM) to model the interaction between aggregate and geogrid. The DEM technique, which allows engineers to construct virtual models and simulations, provides insight into the mechanisms that enable a geogrid to improve pavement performance through layer stiffness enhancement, stiffness retention and an improvement in bearing capacity (Figure 5).

Tensor partnered with Itasca Consultants GmbH, a company with some of the world's leading experts in the science of numerical modeling. Itasca has pioneered and refined the use of DEM in geotechnical engineering applications.

Working with Tensor's Technology Development Team, Itasca Consultants used DEM technology to model geogrid-stabilized pavements by accurately defining the geometry and physical characteristics of Tensor Geogrid and aggregate base course materials.⁴ Interactions between geogrid and soil materials at a near-molecular level facilitated the simulation of a rolling wheel. The models helped explain how the geogrid contributes to the development of residual stresses and how these stiffen the soil layer surrounding the geogrid, which leads to enhanced overall pavement performance. Through computer models such as DEM, the mechanisms specific to geogrid reinforcement in paved applications were better defined and quantified such that small- and full-scale validation research could be performed.

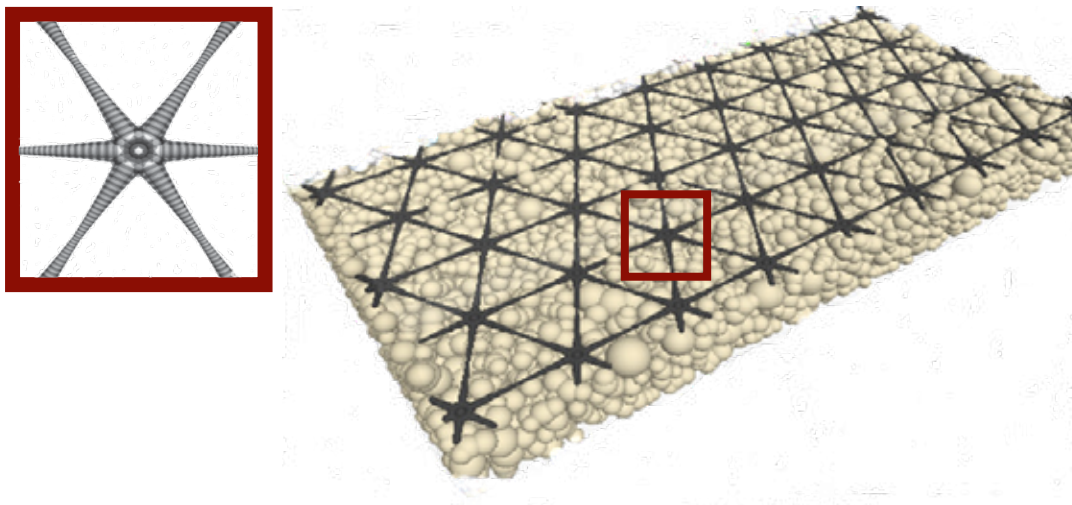


FIGURE 5 *These images of DEM modeling show the use of spherical particles to represent TriAx Geogrid and aggregate.*

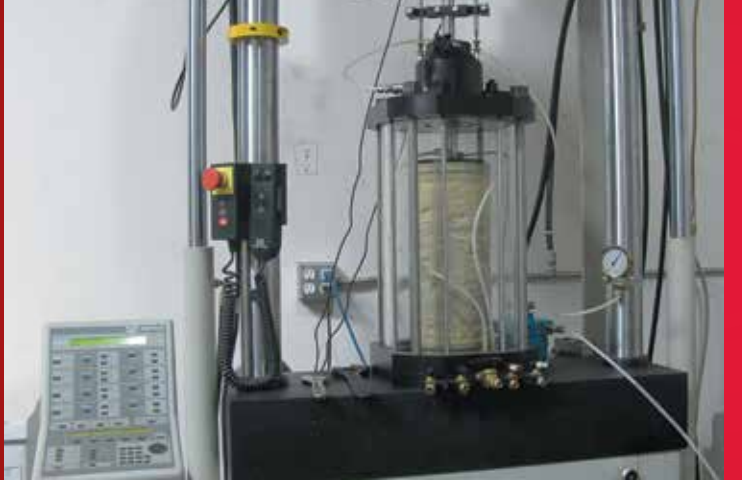


FIGURE 7 Small-scale research through a modified resilient modulus test confirms the stiffness enhancement achieved through the inclusion of a TriAx Geogrid within a crushed aggregate layer.

Lateral Restraint and Retained Stiffness of Aggregate Base

Lateral restraint is defined as the ability of the geogrid rib members to prevent lateral movement of aggregate particles. This confinement mechanism creates a number of immediate and long-term features in paved road applications, including:

- ▶ Uniform compaction of an aggregate base layer
- ▶ Reduction in both surface and sub-surface rutting
- ▶ Retention of stiffness of the aggregate base layer, resulting in less distress to the pavement structure

TRIAXIAL CELL TESTING

The amount of aggregate confinement achieved is determined by the efficiency of the stress transfer that occurs between the individual aggregate particles and the geogrid. This is a function of the aggregate gradation (more efficient transfer takes place with well-graded materials) and the geometry and integrity of the geogrid ribs. Based on the results of the small-scale wheel and DEM tests described on pages 8 and 9, it was determined that a tall, thin geogrid rib would outperform the thinner, flat rib of a Tensar Biaxial Geogrid (Figure 6).

In order to investigate this phenomenon further, repeated load triaxial cell testing was undertaken (Figure 7). Repeated load testing is effectively a modified form of the conventional resilient modulus test. The results (Figure 8) clearly validated the previous testing. Specifically, both the biaxial and Tensar TriAx Geogrids are able to maintain the enhanced aggregate stiffness relative to a control section – notice the steep curve for the control section after 50,000 load cycles. Also, Tensar TriAx Geogrid provides a greater stiffness enhancement relative to conventional biaxial geogrid. The greater stiffness enhancement reduces rutting and asphalt fatigue under repeated traffic loading.

The application of multiple stress levels during the triaxial testing facilitated an evaluation of the relative contribution of Tensar TriAx Geogrid under the different stress levels likely to be encountered within a pavement structure. Given that the stresses generated within a pavement vary depending on the total pavement thickness and the subgrade strength (among other factors), the results from the triaxial testing can be used to predict the increase in base layer modulus provided by a Tensar TriAx Geogrid for a specific set of design conditions.

TRIAx VS. BIAxIAL COMPARISON

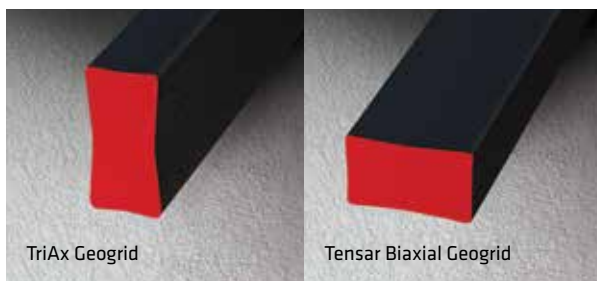


FIGURE 6 Cyclic loading using a modified resilient modulus test confirmed that the efficient rib profile and multi-axial rib orientation of TriAx Geogrid results in a more effective product than Tensar Biaxial Geogrid.

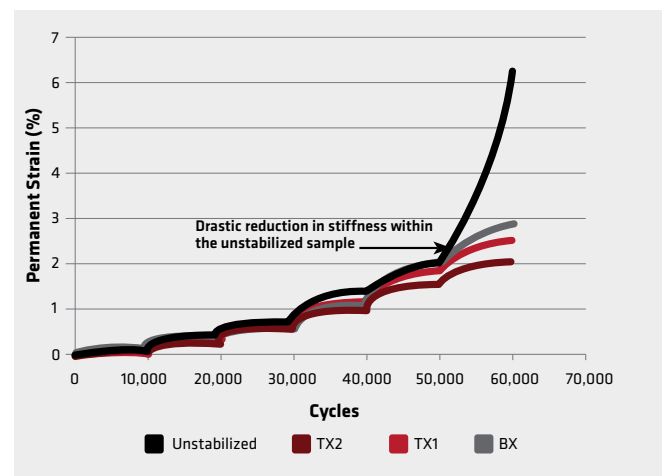


FIGURE 8 Triaxial cell testing results.



The large 9 foot diameter cylinder at BRE was used to determine the bearing capacity improvement for Tensor TriAx Geogrids.

Bearing Capacity Improvement Through Mechanical Stabilization

In thinner flexible pavement applications or sections over soft soils, the subgrade strength will generally determine overall performance through rutting accumulation in the asphalt, the aggregate and the subgrade itself. Geogrid stabilization has been shown to significantly improve the ability to distribute load over soft soils, particularly in unpaved applications. The concept of bearing capacity improvement is well-documented for haul roads and unpaved working surfaces; however, in paved applications it was generally not considered to be a relevant mechanism. We now understand that this mechanism is valid for relatively thin flexible pavements ($ACC \leq 4$ in.) constructed over soft foundation soils. Full-scale research performed at the British Research Establishment (BRE) in the United Kingdom confirms that mechanical stabilization utilizing Tensor TriAx Geogrid significantly improves bearing capacity.

Unique to the large-scale testing performed at BRE was the utilization of a nearly 9 ft. diameter cylinder to effectively eliminate any additional confinement due to “edge effects.” Plate load testing and careful instrumentation of each soil layer for the unstabilized base yielded the stress bulb shown in Figure 9A. This indicated a punching failure of the subgrade soil, with load spread that was almost vertical from the edges of the plate. Displacement of the aggregate was measured at a significant depth. However, the section stabilized with TriAx Geogrid, loaded at more than twice the unstabilized section, demonstrated a much wider stress distribution, mostly concentrated within the stabilized zone (see Figure 9B).

The research confirmed that a mechanically stabilized layer incorporating Tensor TriAx Geogrid reduces subgrade stress, thus improving bearing capacity. Through this large-scale testing, pressure reduction on pavement subgrades can be quantified.

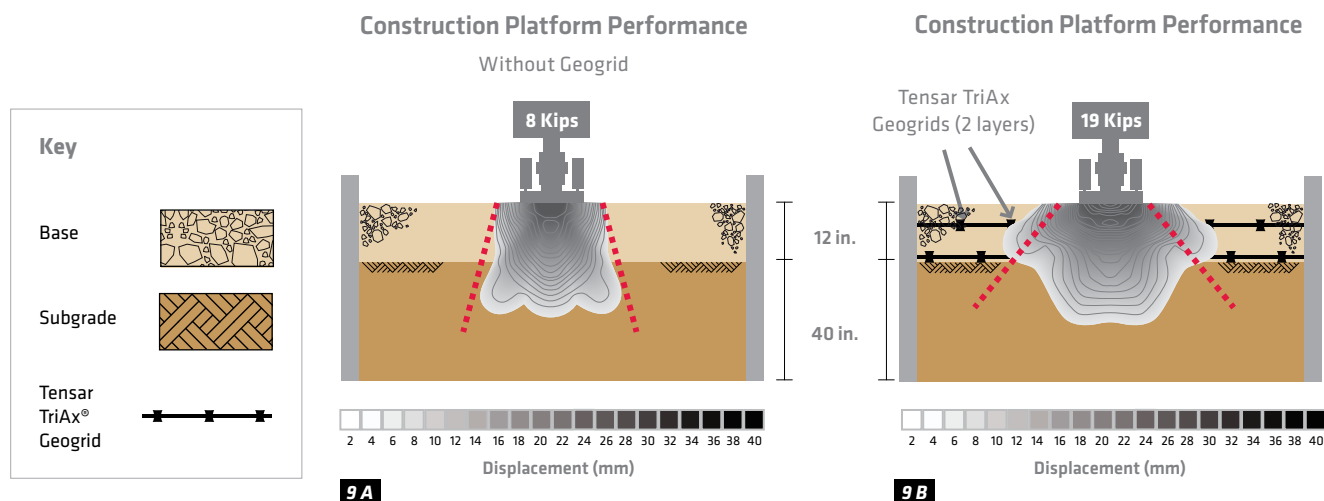


FIGURE 9 The full-scale testing at BRE confirmed significant improvement in bearing capacity through the inclusion of a mechanically stabilized layer (MSL) using Tensor TriAx Geogrid.



The University of Illinois used the Accelerated Transportation Loading System (ATLAS) to test the effectiveness of Tensor Geogrid. The responses of the pavement sections were then measured.

University of Illinois at Urbana-Champaign

Full-scale accelerated pavement testing was conducted at the University of Illinois at Urbana-Champaign (UIUC), under the direction of Dr. Imad L. Al-Qadi and Dr. Erol Tutumluer, to evaluate the performance of Tensor Geogrids in flexible pavements.⁵ The study's main objective was to develop a mechanistic analysis model for the inclusion of geogrids in flexible pavements by testing full-scale sections and measuring the pavement's response to loading using state-of-the-art instrumentation. At UIUC, researchers measured the response to loading using instrumentation beneath and within the pavement structure to quantify stresses and strains at various elevations. This mechanistic data served as the needed validation for the development of the prediction model now employed by Tensor for paved applications.

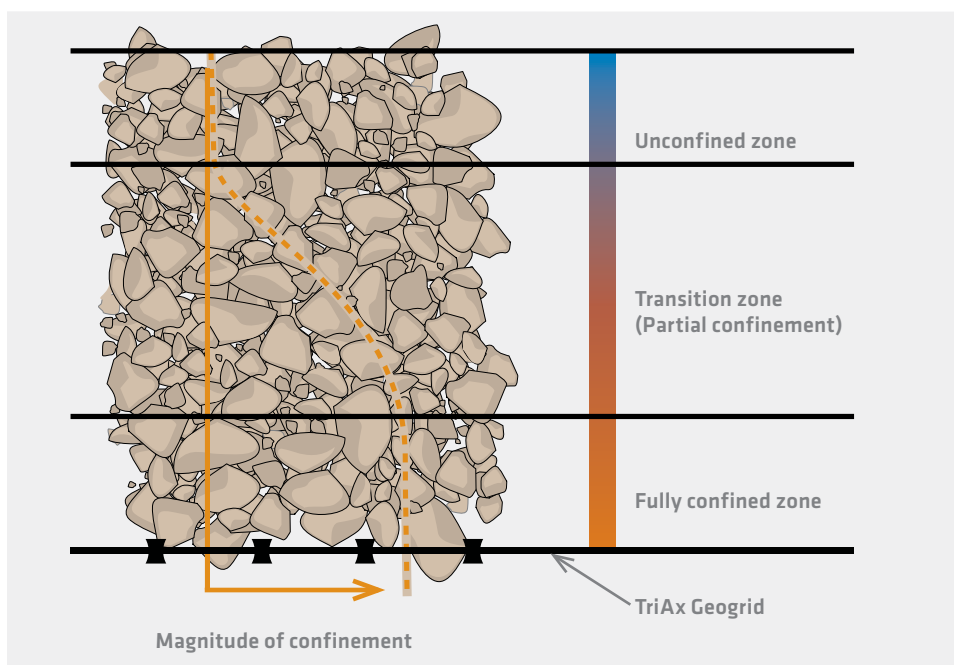
The research at UIUC revealed that Tensor Geogrid has a pronounced impact on the response and performance of the aggregate base course in comparison with unstabilized control

sections. These results validate that stiffness enhancement realized with the geogrid stabilization varied with:

- ▶ Aggregate thickness
- ▶ Asphalt thickness
- ▶ Subgrade support
- ▶ Aggregate quality
- ▶ Geogrid type and depth of placement
- ▶ Moisture, traffic and other factors

These efforts provided Tensor engineers with a definitive means by which to use a mechanistic model to predict the incremental benefit associated with the use of Tensor Geogrid stabilization in flexible pavement applications. This work is also aiding the validation of ongoing full-scale research related to TriAx Geogrid.

Aggregate confinement within a mechanically stabilized layer. An efficient stabilization material such as Tensor TriAx Geogrid increases the magnitude of confinement and increases the thickness of the confined zone.





Excavations through each test section reveal the significant influence of Tensar Geogrid stabilization.

The full-scale evidence at UIUC provided further insight into the stabilization mechanisms and the benefit of Tensar Geogrid in flexible pavements. Carefully instrumented trafficking trials helped to quantify the near isotropic stiffness characteristics offered by geogrid under moving wheel loads to better simulate and predict real-world conditions.

UIUC researchers utilized accelerated pavement testing (APT) to compress years of vehicular traffic into a relatively short period. Measurements under different load levels indicated that the geogrid's enhanced "snowshoe effect" and lateral confinement mechanisms improve pavement responses such as tensile strains at the bottom of the asphalt, vertical pressure and strains on top of the subgrade, and lateral movements in the aggregate base layer.

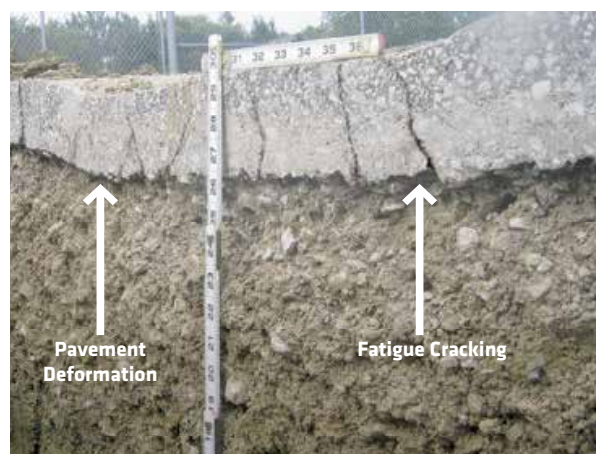
One of the key findings from the UIUC research is demonstrated in Figure 10. These two photographs were taken of the side of an excavation trench following trafficking. It is clear that in the unstabilized section significant vertical displacement and fatigue cracking of the asphalt has taken place due to the weakening and movement of the underlying aggregate. By contrast, in the geogrid-stabilized section, the aggregate stiffness has been maintained and therefore the overlying asphalt has remained intact with significantly less vertical displacement.

A GLIMPSE INTO THE FUTURE: MECHANISTIC-EMPIRICAL DESIGN

As detailed on page 7, the inclusion of geogrids in pavement design has historically been based on a purely empirical approach. Full-scale trials were undertaken to accurately define the performance benefit a particular geogrid offered using the concept of a traffic benefit ratio (TBR). While these techniques have served the industry well and are still used today, there are a number of disadvantages in adopting this approach. One of the main issues, for example, is that only surface rutting is considered in this form of analysis.

The research undertaken at UIUC was the most extensive ever performed on geogrid-stabilized pavement structures. Each test section was fully instrumented with a series of stress and strain sensors, providing data that allowed a fundamental understanding of the effects of the traffic loading within each individual layer. By gaining knowledge of the responses of the individual elements of a pavement structure, it is possible to develop a full mechanistic-empirical model that can be used to more accurately define benefits of the geogrid stabilization. This in turn provides the pavement engineer with a more economic and reliable design.

FIGURE 10
The post-trafficked trench section (right) reveals a dramatic reduction in asphalt and aggregate deformation due to the inclusion of Tensar Geogrid when compared to the unstabilized section (left).





Initial Cost Benefits

Engineers have long used the AASHTO Flexible Pavement Design method (1993) as an empirical approach to predict pavement performance. The design procedure prescribes a “cover method” that requires pavement engineers to determine a section of sufficient thickness and stiffness (or structural number, SN) to effectively protect the roadbed soil for the projected service life of the structure.

One way geogrids can be accounted for structurally in a flexible pavement design is addressed by AASHTO’s Standard Practice R 50-09, “*Recommended Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures*.” The allowable traffic load determined for the unstabilized pavement is multiplied by an appropriate traffic benefit ratio (TBR), as defined on page 7. TBR values used for a particular geogrid should be defined through evaluation of the product’s performance in full-scale test sections. Tensar TriAx Geogrid is accounted for in a conventional flexible pavement design through a combination of TBR and enhanced layer stiffness coefficients. Through Tensar’s understanding of how TriAx Geogrids perform in full-scale, finite saving may be calculated such that initial construction and life cycle cost benefits can be quantified.

SAVINGS OFFERED THROUGH UNIT PRICE COMPARISON

Tables 1 and 2 break down the in-place costs associated with both aggregate and asphalt concrete, common building materials for a flexible pavement system. Essential to a cost analysis is knowledge of the in-place price of material components so that a unit price for the total system can be calculated. Each of the tables show a converted price per unit area for the depth of material being considered for design. For example, 12 inches of aggregate base delivered, installed and compacted for a price of \$25.00/ton would equate to a unit cost of \$15.00/SY per Table 2 – Installed Aggregate Cost. Accordingly, if the Tensar TriAx Geogrid required only eight inches of aggregate for an equivalent section, the potential savings would be:

$$\begin{aligned} &\$15.00/\text{SY (12 inches)} - \$10.00/\text{SY (8 inches)} = \$5.00 \\ &\text{minus the in-place cost of Tensar TriAx Geogrid} \end{aligned}$$

Savings may also be realized through asphalt reduction utilizing this same concept. End users who seek the initial cost benefits using TriAx Geogrid are encouraged to perform a cost sensitivity analysis.

INSTALLED ASPHALT COST (\$/SY)															
Asphalt Thickness (inches)	In-Place Cost of Asphalt (\$/ton)														
	\$20.00	\$30.00	\$40.00	\$50.00	\$60.00	\$70.00	\$80.00	\$90.00	\$100.00	\$110.00	\$120.00	\$130.00	\$140.00	\$150.00	
	0.5	0.56	0.83	1.11	1.39	1.67	1.94	2.22	2.50	2.78	3.05	3.33	3.61	3.89	4.16
	1.0	1.11	1.67	2.22	2.78	3.33	3.89	4.44	5.00	5.55	6.11	6.66	7.22	7.77	8.33
	1.5	1.67	2.50	3.33	4.16	5.00	5.83	6.66	7.49	8.33	9.16	9.99	10.82	11.66	12.49
	2.0	2.22	3.33	4.44	5.55	6.66	7.77	8.88	9.99	11.10	12.21	13.32	14.43	15.54	16.65
	2.5	2.78	4.16	5.55	6.94	8.33	9.71	11.10	12.49	13.88	15.26	16.65	18.04	19.43	20.81
	3.0	3.33	5.00	6.66	8.33	9.99	11.66	13.32	14.99	16.65	18.32	19.98	21.65	23.31	24.98
	3.5	3.89	5.83	7.77	9.71	11.66	13.60	15.54	17.48	19.43	21.37	23.31	25.25	27.20	29.14
	4.0	4.44	6.66	8.88	11.10	13.32	15.54	17.76	19.98	22.20	24.42	26.64	28.86	31.08	33.30
	4.5	5.00	7.49	9.99	12.49	14.99	17.48	19.98	22.48	24.98	27.47	29.97	32.47	34.97	37.46

TABLE 1

► Using Tensor TriAx Geogrid can reduce asphalt thickness by 15-30% and aggregate thickness by as much as 25-50%.

EXAMPLE PROBLEM - CONSTRUCTION COST SAVINGS

A county road measuring 36 ft. wide and one mile long is designed to carry 1.5 million equivalent single axle loads (ESALs) over 20 years. County engineers wish to construct a typical section that requires a *minimum* of 4 in. of asphalt and 6 in. of aggregate base course. Geotechnical data reveal the pavement subgrade exhibits a CBR = 3.0 ($M_R = 5,161$ psi). Other relevant inputs include:

► **Layer coefficients:**

Asphalt Wearing Course = 0.42
Dense Graded Asphalt = 0.40
Aggregate Base Course = 0.14

► **Other parameters:**

Reliability = 90%
Standard Deviation = 0.49
Change in Serviceability = 2.2

► **Component costs (in-place):**

Asphalt Wearing Course = \$75.00/ton
Dense Graded Asphalt = \$65.00/ton
Aggregate Base Course = \$21.50/ton

Determine the initial cost savings per unit area (\$/SY) and total savings using TriAx Geogrid.

SOLUTION:

The required pavement thicknesses calculated using the AASHTO (1993) design method are shown below, along with the relevant costs:

Conventional		With TriAx Geogrid	
Asphalt Wearing Course:	2 inches	Asphalt Wearing Course:	2 inches
Dense Graded Asphalt:	5 inches	Dense Graded Asphalt:	3 inches
Aggregate Base:	9 inches	Aggregate Base:	8 inches
		TriAx Geogrid	
Unit Cost:	\$36.04/SY	Unit Cost:	\$27.75/SY plus TriAx installed cost
Total Cost:	\$761,000	Total Cost:	\$586,000 plus TriAx installed cost
Total Savings:	—	Total Savings:	\$175,000 minus TriAx installed cost

NOTE: The conventional pavement required is significantly thicker than the county's minimum standard pavement section.

For pricing information on Tensor TriAx Geogrid or to locate a local stocking distributor, please call 800-TENSAR-1.

INSTALLED AGGREGATE COST (\$/SY)															
Compacted Aggregate Base Thickness (inches)	In-Place Cost of Aggregate Base (\$/ton)														
	\$5.00	\$6.00	\$7.00	\$8.00	\$9.00	\$10.00	\$15.00	\$20.00	\$25.00	\$30.00	\$35.00	\$40.00	\$45.00	\$50.00	
4	1.00	1.20	1.40	1.60	1.80	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	
5	1.25	1.50	1.75	2.00	2.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	
6	1.50	1.80	2.10	2.40	2.70	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	
7	1.75	2.10	2.45	2.80	3.15	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.75	17.50	
8	2.00	2.40	2.80	3.20	3.60	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	
9	2.25	2.70	3.15	3.60	4.05	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	
10	2.50	3.00	3.50	4.00	4.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	
11	2.75	3.30	3.85	4.40	4.95	5.50	8.25	11.00	13.75	16.50	19.25	22.00	24.75	27.50	
12	3.00	3.60	4.20	4.80	5.40	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00	

TABLE 2

► TriAx Geogrid reduces the number of rehabilitation intervals, which reduces life cycle costs.



Life Cycle Cost Benefits of Tensar® TriAx® Geogrids

Tensar TriAx Geogrid provides significant cost savings during construction and over the long-term. Life cycle cost analysis (LCCA) provides a method of quantifying the present worth of future costs associated with the maintenance and rehabilitation of civil engineering structures. In simple terms, LCCA demonstrates that by spending slightly more up front, project owners can realize significant savings over the long-term.

LCCA is applicable to the utilization of geogrid stabilization in flexible pavement structures. Calculated life cycle cost savings are based upon extending the long-term service life of the paved structure, thereby reducing the total number of maintenance and rehabilitation intervals. It allows design engineers to compare the present worth of pavement options with different construction costs and performance expectations over specified periods of time. An analysis would include the expense of the Tensar TriAx Geogrid (typically less than 15% of a pavement structure's total in-place cost) as well as the pavement component costs and a comparison to the present worth of costs (PWOC) of typical maintenance (i.e., chip seal, crack filling) and rehabilitation (asphalt overlay) intervals.

EXAMPLE PROBLEM – LIFE CYCLE COST BENEFITS

A low-volume county road is designed to carry 400,000 equivalent single axle loads (ESALs) over 20 years. Historical costing data reveals the county's typical pavement section requires maintenance every three years and rehabilitation every six years. Pavement subgrades average a support value of CBR = 7 ($M_R = 8,877$ psi). Pavement design inputs for layer stiffness, component costs and county-specified minimum thicknesses are identical to the initial cost example shown on page 15 (assume \$75/ton for the general asphalt cost). Maintenance and rehabilitation interval costs catalogued by the county used for performing a life cycle cost analysis are shown below:

- Maintenance (Surface Seal): \$115,000
- Rehabilitation (Structural Overlay and Surface Seal): \$155,000
- Discount Rate: 4%
- Design Service Life: 20 years

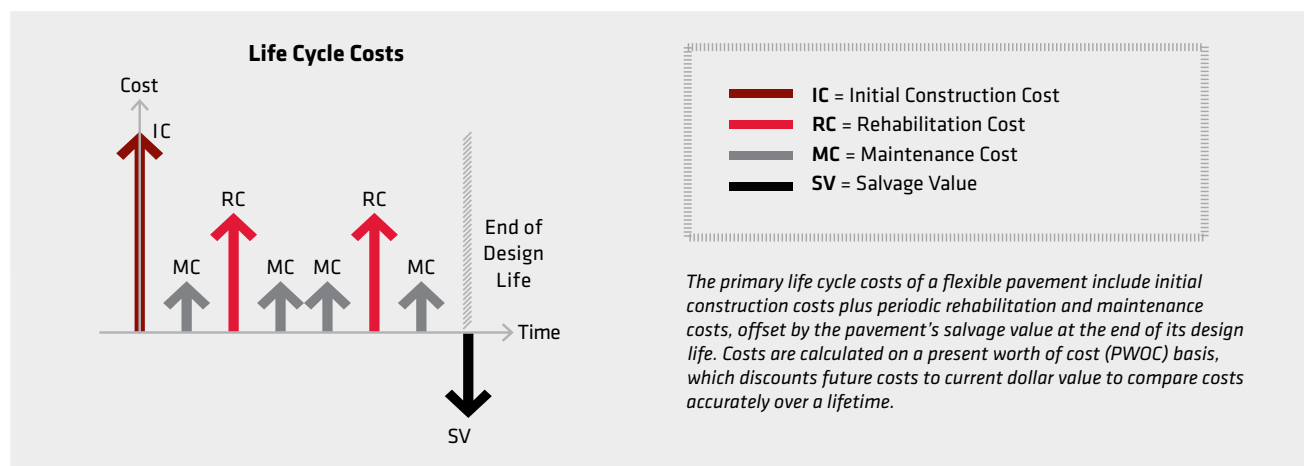


TABLE 3

Activity Timing & Interval Costs						
Conventional				Tensor TriAx Geogrid Stabilized		
Year	ESALs	Maintenance	Rehabilitation	ESALs	Maintenance	Rehabilitation
3	60,000	\$ 115,000.00		60,000		
6	120,000	\$ 115,000.00	\$ 155,000.00	120,000		
9	180,000	\$ 115,000.00		180,000	\$ 115,000.00	
12	240,000	\$ 115,000.00	\$ 155,000.00	240,000		
15	300,000	\$ 115,000.00		300,000		
18	360,000	\$ 115,000.00	\$ 155,000.00	360,000	\$ 115,000.00	\$ 155,000.00
	Sub-Totals	\$690,000.00	\$ 465,000.00	Sub-Totals	\$230,000.00	\$155,000.00
	Total		\$1,155,000.00	Total		\$385,000.00

Determine the present worth of cost (PWOC) of a conventional pavement section compared to an equivalent thickness stabilized with Tensor TriAx Geogrid.

SOLUTION:

- **Step 1:** Establish Design Alternatives and Initial Construction Costs

	Conventional	TriAx Geogrid
Asphalt:	4 inches	4 inches
Aggregate Base:	8 inches	8 inches
Design ESALs:	425,000	1,829,000
Initial Cost:	\$533,000	\$597,000

The AASHTO 1993 design method component thicknesses of the conventional pavement section and a section stabilized with Tensor TriAx Geogrid are shown below:

- **Step 2:** Determine Activity Timing and Internal Costs

The maintenance and rehabilitation intervals for the TriAx Geogrid stabilized section are assumed based on local experience. The effects on total cost during the pavement's design life are presented in Table 3.

- **Step 3:** Compute Life Cycle Costs

Using the discount rate (4%), the present worth of cost (PWOC) is calculated for each of the maintenance and rehabilitation events, as shown in Table 4 (Salvage Value is assumed to be the same for both pavement alternatives at year 20; therefore, the effect on the overall calculation is negligible).

$$\text{Discount Factor} = 1 / (1 + r)^n$$

Where:

r = discount rate (%), expressed as a decimal (e.g., 4% = 0.04)

n = number of years in the future when cost will be incurred

- **Step 4:** Analyze the Results

Even though using Tensor TriAx Geogrid results in a 12% higher initial cost to the owner at the time of construction, the life cycle cost saving is **37% lower** than for a conventional pavement section.

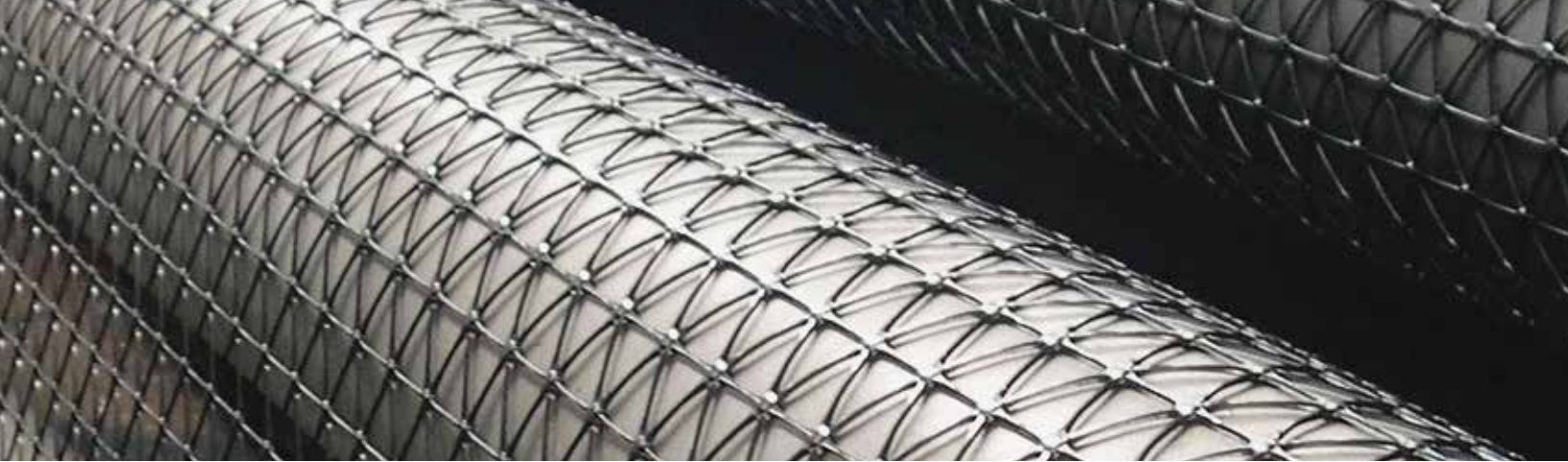
Based upon the needs of the end user, TriAx Geogrid can be considered a valuable solution for flexible pavement applications to save money both now and later.

Life Cycle Costs							
Conventional					Tensor TriAx Geogrid Stabilized		
Year	Discount Factor	Initial Cost	Maintenance	Rehabilitation	Initial Cost	Maintenance	Rehabilitation
0	1.0000	\$533,000			\$597,000		
3	0.8890		\$ 102,234.58				
6	0.7903		\$ 90,886.17	\$ 122,498.75			
9	0.7026		\$ 80,797.47			\$ 80,797.47	
12	0.6246		\$ 71,828.66	\$ 96,812.54			
15	0.5553		\$ 63,855.42				
18	0.4936		\$ 56,767.23	\$ 76,512.36		\$ 56,767.23	\$ 76,512.36
	Sub-Totals	\$533,000	\$466,369.54	\$ 295,823.65	\$597,000	\$137,564.71	\$ 76,512.36
	PWOC Total			\$1,295,193.19			\$811,077.07

TABLE 4

Additional Cost
LCC Saving

12%
37%



Design Tools

SPECTRAPAVE SOFTWARE

Tensar's industry-leading design and analysis tool, SpectraPave Software, allows the user to accurately predict the performance of geogrid stabilized and unstabilized structures for both paved and unpaved applications. The software offers two cost analysis tools to evaluate design options for paved and unpaved roads.

UNPAVED APPLICATIONS - HAUL ROADS AND WORKING SURFACES

Developed in accordance with the latest Giroud-Han design methodology, the unpaved module allows the designer to consider the cost benefits of using a mechanically stabilized layer (MSL) incorporating Tensar TriAx Geogrids. Similar sections containing geotextiles or other geogrid materials can also be analyzed. The program output includes a breakdown of aggregate savings, undercut savings and overall project cost savings.

PAVED APPLICATIONS - FLEXIBLE PAVEMENTS

The paved module was developed to allow the designer to consider the benefits of using Tensar TriAx Geogrids in flexible pavement applications considering both traffic benefit ratio (TBR) and enhanced aggregate layer stiffness coefficients. The calculations employed are in full accordance with AASHTO's (1993) Flexible Pavement Design Guide.

COST ANALYSIS TOOLS

Both modules within SpectraPave allow users to calculate the bottom-line savings potential of Tensar TriAx Geogrids. The Unpaved Applications module accounts for fill, undercut, installation and geosynthetic costs to deliver both unit area and lump sum potential cost savings. The Paved Applications module includes both initial cost savings and comprehensive life cycle cost analysis (LCCA) such that both short- and long-term savings using the TriAx Geogrid can be determined.

SpectraPave Software is available to registered users via download from our website, www.TensarCorp.com. You may also request a copy of SpectraPave by calling **800-TENSAR-1** or by contacting your local Tensar representative.

Tensar's SpectraPave Software is an industry-leading analysis tool that leverages more than three decades of full-scale research and practical experience.





The Solution That Works Every Time

THE TENSAR ADVANTAGE

For more than 30 years, industry professionals have been using Tensar Geogrids to build economical, long-lasting structures. With clear advantages in performance, design and installation, Tensar offers a proven technology for addressing the most challenging projects.

Our entire worldwide distribution team is dedicated to providing the highest quality products, services and support. With a technically trained sales staff and an in-house and regional engineering department, Tensar International Corporation keeps its technical solutions at the forefront of today's design technology and market needs.

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- ² AASHTO. (1993). *AASHTO Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C.
- ³ AASHTO. (2013). *Recommended Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures*. AASHTO Publication R50-09. American Association of State Highway and Transportation Officials, Washington, D.C.
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For more information on Tensar TriAx Geogrid, call **800-TENSAR-1**, visit **www.TensarCorp.com** or email **info@tensarcorp.com**. We are happy to supply you with additional information on our geogrid products, installation guidelines, system specifications, design details, conceptual designs, preliminary cost estimates, case studies, software and more.



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