Improvement of Roads with Geogrid

- Primary function is reinforcement through
- a.) lateral restraint,
  b.) improved bearing capacity and
  c.)tensioned membrane effect.
- Reduce costs by reducing pavement structure thicknesses and increases pavement life

Prepared By : Rebwar Abdullrahman M.

Paved Roads and the Need for Innovation

Conventional construction practices are presenting new challenges to pavement engineers, contractors and owners due to the volatility of material costs and their availability. 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
- Pavement material availability due to supply shortages
- Pavement life span being compromised due to increased trafficking, insufficient pavement structure, reduced maintenance budgets, etc.

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

Presently, there exists a need for innovation for paved road applications. A growing number of transportation professionals are considering designs that incorporate The Spectra System offers design and material components that make it one of the industry's leading solutions for creating mechanically stabilized pavement structures, but it now also includes a groundbreaking triangular reinforcement geogrid – Tensar® TriAx® Geogrid.

A BREAKTHROUGH TECHNOLOGY

In combination with the Spectra System'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 Geogrid 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.

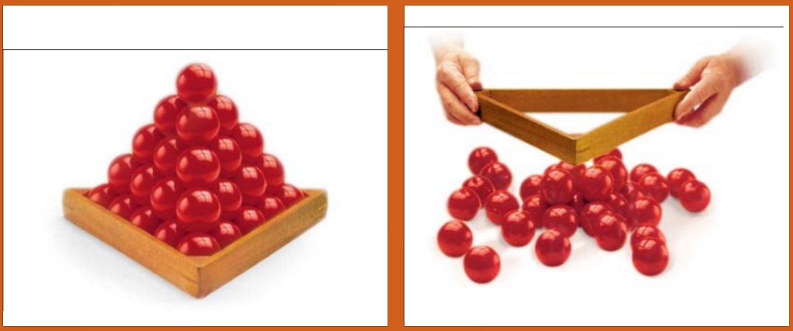
COST-EFFECTIVE PAVEMENT DESIGN

The Spectra® System with Tensar® TriAx® Geogrid is supported by years of laboratory research, full-scale testing and practical experience in the field. Numerous worldwide studies and installations have proven that the mechanically stabilized base layer in the Spectra System 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 the pavement component thickness can be achieved with the Spectra Roadway Improvement System:

- Reduction of asphalt layer: 15-30%
- Reduction of aggregate layer: 25-50%

Cost savings are realized through reduction of raw material usage and through hauling and placement charges. (See construction cost benefit example on page 15.)



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

Key Mechanisms – Lateral Restraint and Load Spread

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

Reduced Life Cycle Costs: Through the unique properties of TriAx Geogrids, the Spectra System offers engineers, contractors and owners a solution that extends the service life of a pavement structure, sometimes by as much as 500%! This feature offers reduced maintenance and extends rehabilitation intervals which yields 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. As such, the benefits provided by the Spectra Roadway Improvement System 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.

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 has been proven to improve the performance of the pavement system. If the subgrade is weak, an additional layer of aggregate and Tensar TriAx Geogrid can be used to strengthen it before placing the geogrid reinforced base layer.

LATERAL RESTRAINT IS THE KEY TO AGGREGATE STIFFENING

The U.S. Army Corps of Engineers reported in an engineering technical letter[1] 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 considered to be stress-dependent materials, the confinement offered by properly designed, stiff 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 reinforced 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 specific to Tensar TriAx Geogrids, thicknesses may be optimized for both light-duty and heavy-duty flexible pavement sections. Refer to Figure 2 for an illustration of this key performance mechanism.

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 for the purposes of yielding a stable working surface. However, it also applies to pavement structures, particularly flexible pavements reinforced 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

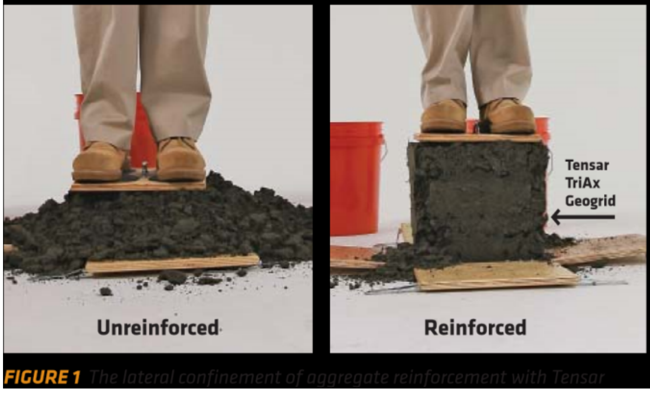


FIGURE 1 *The lateral confinement of aggregate reinforcement with Tensar TriAx Geogrid is demonstrated through the box of rocks demonstration.*

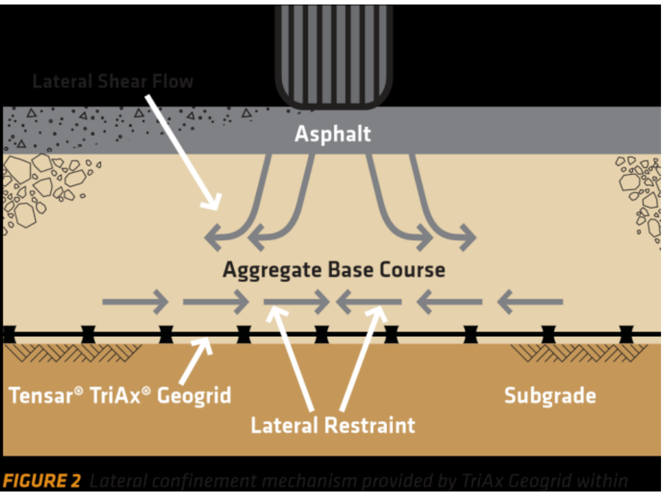


FIGURE 2 *Lateral confinement mechanism provided by TriAx Geogrid within a flexible pavement section.*

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

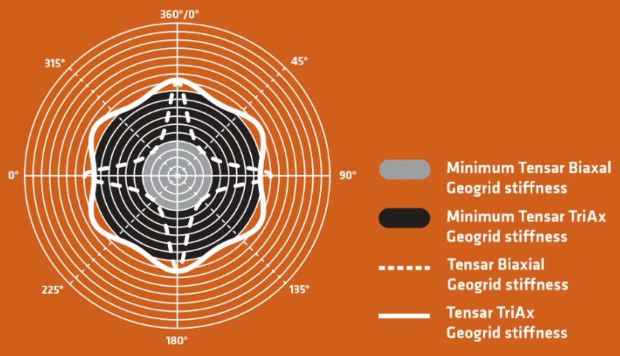


FIGURE 5 *Tensile testing indicates that the triangular structure of TriAx® Geogrid provides a near-isotropic in-plane stiffness when measured in any direction.*

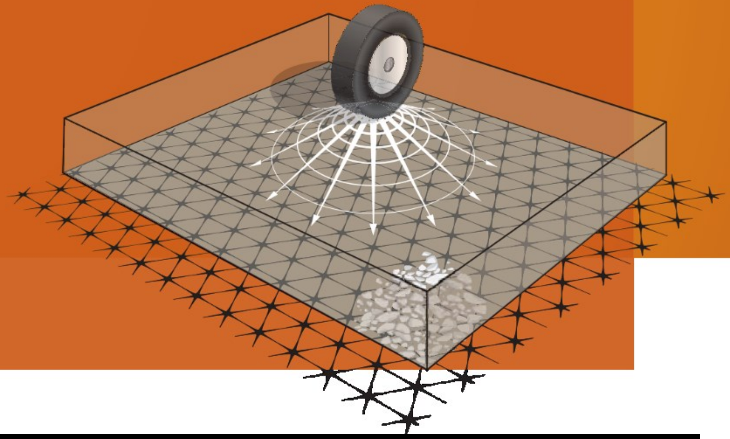


FIGURE 6 *Tensar® TriAx Geogrid is designed to better distribute radial stresses imparted through conventional wheel trafficking. Its triangular structure and efficient rib profile make it a superior geogrid to Tensar's Biaxial (BX) Geogrid.*

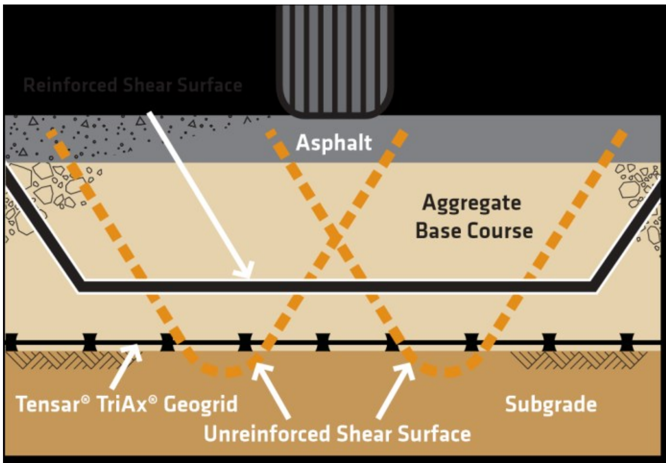


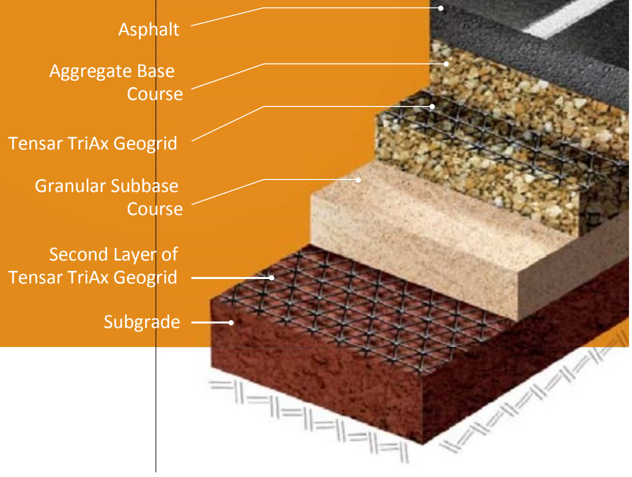
FIGURE 3 *Bearing capacity improvement mechanism shown through the inclusion of Tensar TriAx Geogrid at the aggregate base course-subgrade interface.*

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

Tensar® TriAx® Geogrids were developed with a specific purpose in mind – provide significant performance and cost saving benefits relative to all geogrids currently on the market. Figure 5 compares the tensile stiffness of a Tensar TriAx Geogrid with a Tensar® Biaxial Geogrid. For a Biaxial Geogrid, there is high stiffness in the two orthogonal directions but significantly lower stiffness in between. In contrast, the unique triangular shaped apertures of the Tensar TriAx Geogrid ensure that high tensile stiffness is maintained in all directions. Research has demonstrated the significant radial stresses occur under moving wheel loads (Figure 6). Hence it is not surprising that a Tensar TriAx Geogrid significantly outperforms a Tensar Biaxial Geogrid in side-by-side pavement trials.

> The Spectra® System extends the life of a roadway through the introduction of a mechanically stabilized layer (MSL) within the pavement structure.

FIGURE 7 *The Spectra System may include a second layer of Tensar TriAx Geogrid.*

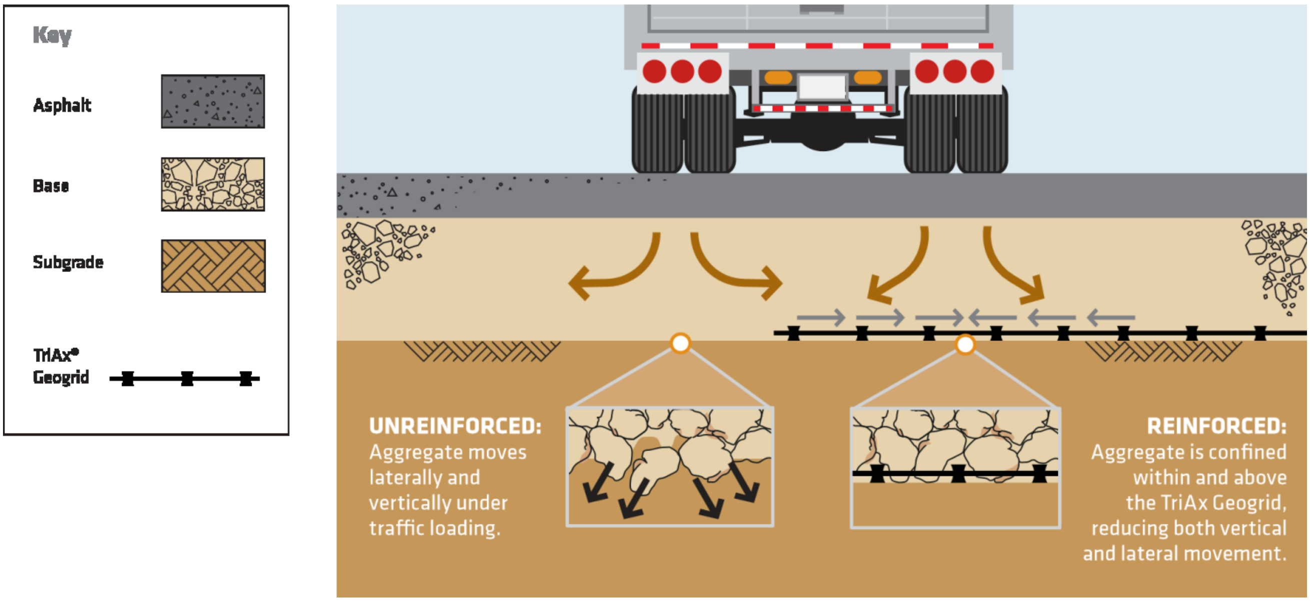


Paved Solutions – Tensar® TriAx® Geogrid Features

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 leading to eventual cracking of the pavement surface. The Spectra® System featuring Tensar® TriAx® Geogrid provides a mechanically stabilized layer (MSL) within either the aggregate base or granular subbase, thereby maintaining structural capacity and improving the long-term performance of the pavement system.

In flexible pavement structures, Tensar TriAx Geogrids are traditionally used to reinforce 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 Tensar TriAx Geogrid may be required within this lower unbound aggregate layer (Figure 7).

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 reinforcement 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, thanks to the enhanced stiffness of the underlying mechanically stabilized aggregate base course in the Spectra System, a reduction in the required thickness of the overlying asphalt cement and concrete may also be realized with Tensar TriAx Geogrid. Based on the data currently available, for typical pavement structures, it is anticipated that the asphalt thickness can be reduced up to 30%.

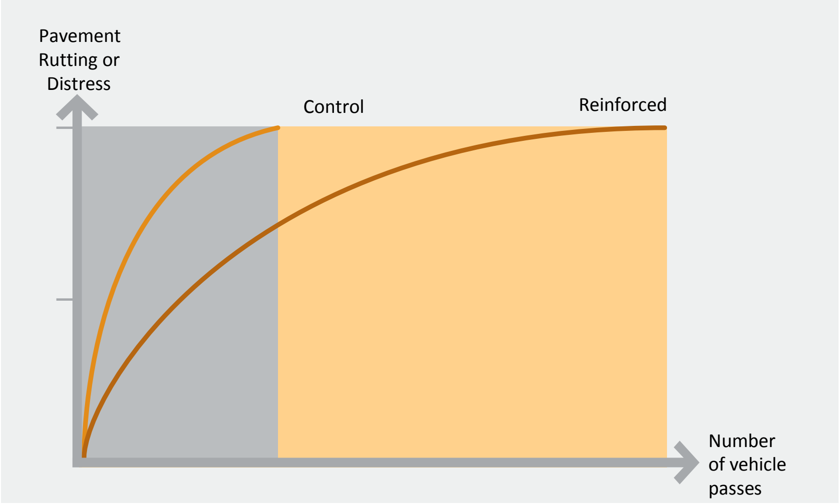
INCREASE PAVEMENT LIFE

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] define such a parameter as the traffic benefit ratio (TBR). This is defined as the ratio of cycles-to-failure in a geogrid-reinforced pavement section compared with an unreinforced 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 reinforcement used.

Further details on how to quantify the benefits of using geogrid reinforcement in pavement structures is provided by AASHTO.[3] 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.



Extension of pavement life with the Spectra® System.

Instrumentation of full-scale, geogrid-reinforced test sections has demonstrated that not only does Tensar® TriAx® Geogrid increase the stiffness of the aggregate layer, the enhanced stiffness is 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.

This use of geogrid technology is not just confined to relatively light-duty pavement structures. Several projects have been undertaken demonstrating that mechanically stabilized layers can also be used to provide the same benefits in thicker, heavy-duty pavement structures where the asphalt cement concrete exceeds 6 in.

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

Research: Relevant Proof to Quantify

The Tensar® TriAx® Geogrid Benefits

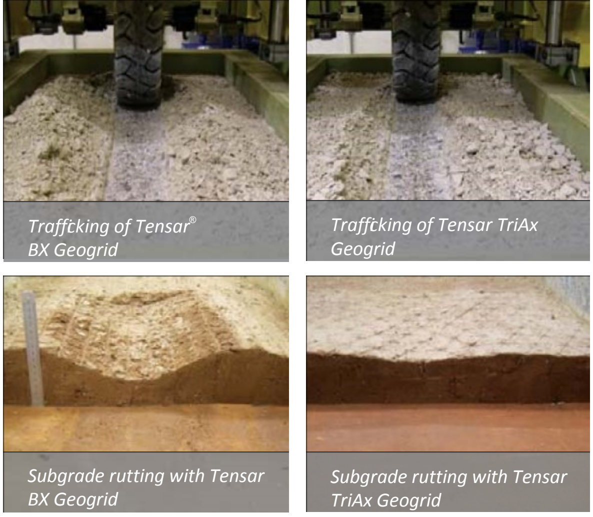
The Spectra® System has a long history of use by the Federal Highway Administration (FHWA), state DOTs, county and municipal agencies as well as private owners and developers. It has consistently demonstrated its economic and structural value in both paved and unpaved applications. Many of these same entities have invested in testing to quantify for themselves the value associated with geogrid reinforcement 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 alike seek means to make their pavement investment go farther and last longer. However, the cost benefits of a new innovation like Tensar® TriAx® Geogrid must be substantiated through relevant proof such as research and practical experience.

DOES TRI AX OUTPER FORM GEOGRID ?

Yes, in order to fully appreciate the potential value of

Tensar TriAx Geogrid for paved applications, a significant investment in research was made by Tensar International Corporation (Tensar) during the development phase of this new technology. Tensar's Product Development Team was challenged with producing 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 over 25 years, Tensar® BX Geogrid. A series of research projects were embarked upon 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 stiff ness enhancement and retention

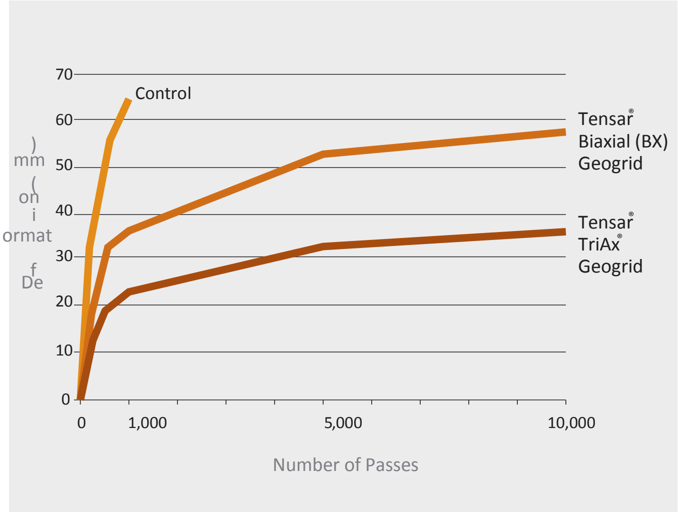

Trafficking of Tensar® BX Geogrid

Trafficking of Tensar TriAx Geogrid

Subgrade rutting with Tensar BX Geogrid

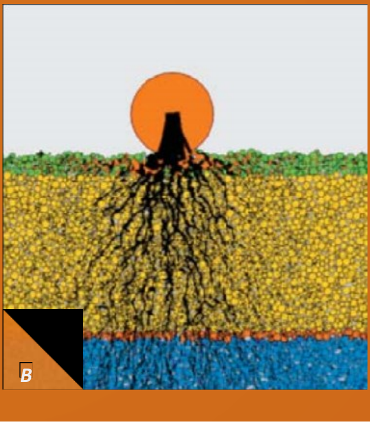
Subgrade rutting with Tensar TriAx Geogrid

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) *Tensar TriAx Geogrid interlocks with 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.*

Based upon the research evidence, the unique aperture geometry and multi-axial confinement potential of Tensar® TriAx® Geogrid offers superior performance at even greater value compared to Tensar® BX Geogrid for paved and unpaved applications.

GROUND BREAKING COMPUTER MODELING

Tensar 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 Tensar TriAx Geogrid and new methods for predicting performance such as the Tensar MechanisticEmpirical (M-E) Pavement Design Method. While developing the Tensar M-E method, our research team used for the first time 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 8).

This groundbreaking collaboration is 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 Tensar's Technology Development Team, ITASCA Consultants were able to use DEM technology to model geogrid-reinforced pavements by accurately defining the geometry and physical characteristics of Tensar 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. These models helped explain how the geogrid contributes to the development of residual stresses and how these stiffen the soil layer surrounding the geogrid leading 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.

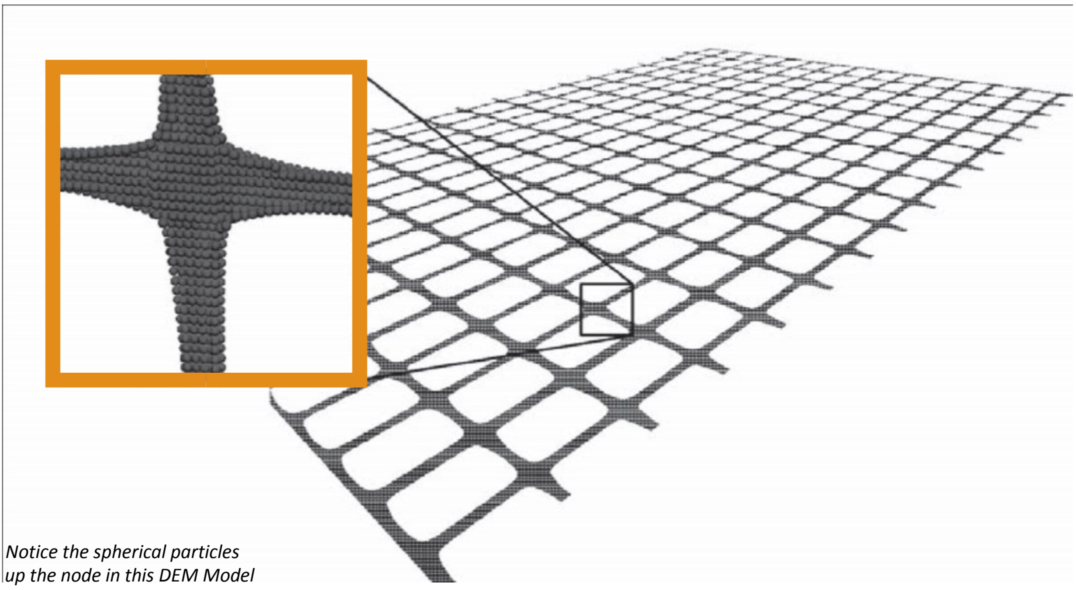


FIGURE 8 *Notice the spherical particles that make up the node in this DEM Model of Tensar Biaxial Geogrid.*

Research: 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 translates into 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 stiff ness 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 respectively, it was determined that a tall, thin geogrid rib would outperform the thinner, flat rib characteristic of a Tensar® Biaxial Geogrid (Figure 9).

In order to investigate this phenomenon further, repeated load triaxial cell testing was undertaken (Figure 10). This type of testing is effectively a modified form of the conventional resilient modulus test. The results (Figure 11) clearly validated the results seen in the previous testing. Specifically, it can be seen that 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, it can be seen that Tensar TriAx Geogrid provides a greater stiffness enhancement relative to conventional biaxial geogrid. It is envisaged that this behavior translates directly to a reduction in 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 (amongst other factors) the total pavement thickness and the subgrade strength, 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 9 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.

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, aggregate and the subgrade itself. Geogrid reinforcement 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, its applicability in paved applications was generally not considered to be a relevant mechanism. However, it is now thought that this mechanism is valid for relatively thin flexible pavements (ACC $\leq$ 4 in.) constructed over soft foundation soils. Recent full-scale research performed at the British Research Establishment (BRE) in the United Kingdom confirms that mechanical stabilization utilizing

Tensar® 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 unreinforced base yielded the stress bulb, shown in (Figure 12a). 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 reinforced with TriAx Geogrid, loaded at more than twice the unreinforced, demonstrated a much wider stress distribution, mostly concentrated within the reinforced zone (see Figure 12b).

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

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

Research: University of Illinois at Urbana-Champaign

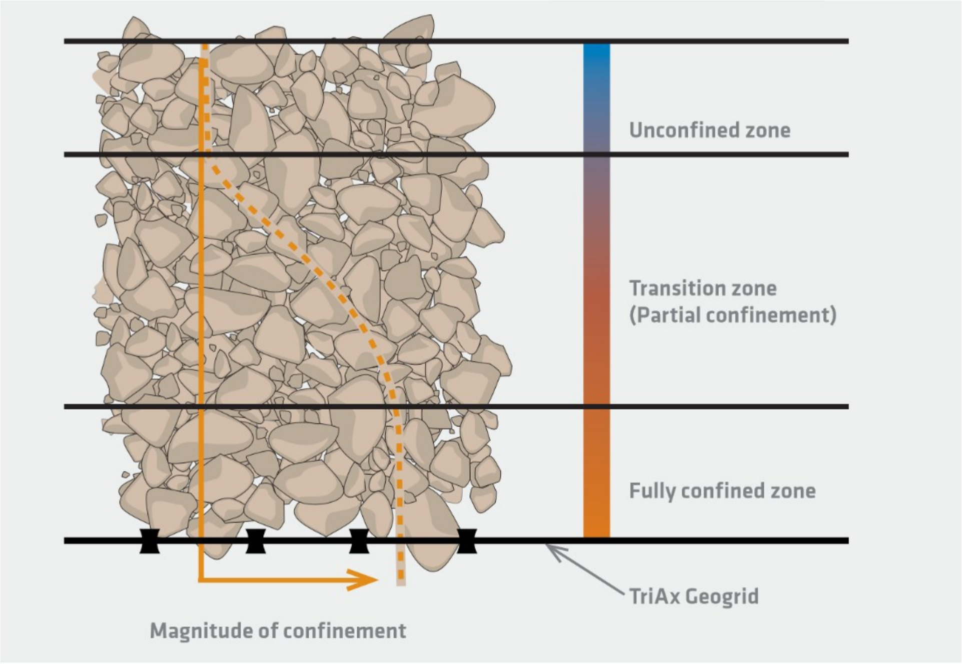
Full-scale accelerated pavement testing was conducted at the University of Illinois at Urbana-Champaign (UIUC), under the direction of Dr. Imad L. Al-Qadi and Dr. Erol Tutumluer, to evaluate the performance of Tensar® Geogrids in flexible pavements.[5] The study's main objective was to develop a mechanistic 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 Tensar for paved applications.

The research at UIUC revealed that Tensar Geogrid has a pronounced impact on the response and performance of the aggregate base course in comparison with unreinforced control sections. These results validate that stiffness enhancement realized with the geogrid reinforcement varied with:

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

These efforts have provided Tensar engineers with a definitive means by which to use a mechanistic model to predict the incremental benefit associated with the use of Tensar Geogrid reinforcement in flexible pavement applications. This work is also aiding the validation of ongoing empirical and mechanisticempirical full-scale research related to the next generation of Tensar Geogrid reinforcement, Tensar® TriAx® Geogrid.

The full-scale evidence at UIUC has provided further insight into the reinforcement mechanisms and benefit of Tensar® Geogrids 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.



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

UIUC researchers utilized accelerated pavement testing (APT) to compress years of vehicular traffic into a relatively short period. Measurements under different load levels indicated how 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.

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

One of the key findings from the UIUC research is demonstrated in Figure 13. These two photographs were taken within the side of an excavation trench following trafficking. It is clear that in the unreinforced section that significant vertical displacement and fatigue cracking of the asphalt has taken place due to the weakening and movement of the underlying aggregate. In contrast, in the geogrid-reinforced section, the aggregate stiffness has been maintained and therefore the overlying asphalt has remained intact with significantly less vertical displacement.

THE 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.

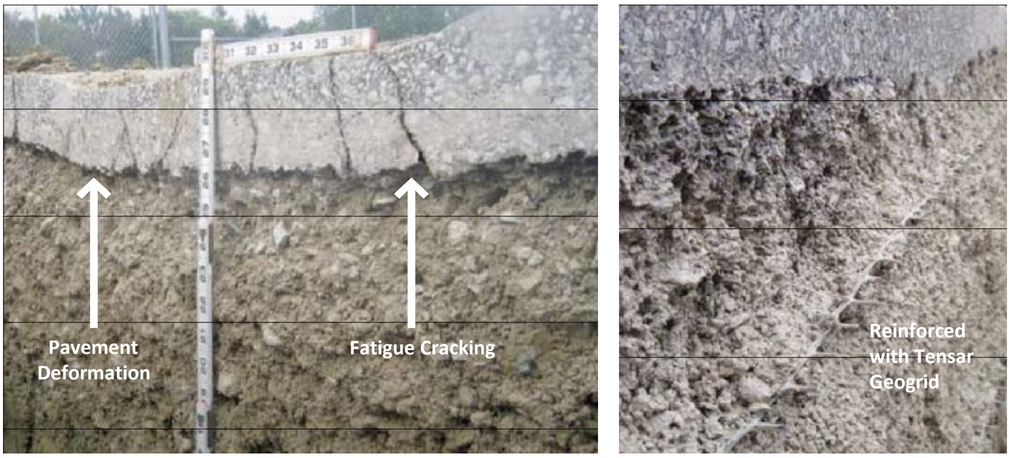


FIGURE 13
The post-trafficked trench section (on the right) reveals a dramatic reduction in asphalt and aggregate deformation due to the inclusion of a Tensar Geogrid when compared to the unreinforced section pictured on the left.

The research undertaken at UIUC was the most extensive ever performed on geogrid-reinforced pavement structures. Each test section was fully instrumented with a series of stress and strain sensors which provided data that allowed us to gain 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 the benefits of the geogrid reinforcement. This in turn provides the pavement engineer with a more economic and reliable design.

Initial Cost Benefits of the Spectra® System

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 Provisional Practice PP 46-01, *"Recommended Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures."* The allowable traffic load determined for the unreinforced 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, a 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 each 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 such that a unit price for the total system can be calculated. Each of these tables offer a converted price per unit area for the depth of material being considered for design. For example, twelve (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 Spectra® System with Tensar TriAx Geogrid required only eight (8) inches of aggregate for an equivalent section, the potential savings realized for the Spectra System would be:

$15.00/SY (12 inches) – $10.00/SY (8 inches) = $5.00 minus the in-place cost of Tensar TriAx Geogrid

The Spectra System featuring Tensar® TriAx® Geogrid offers significant cost savings during construction or over the longterm. 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 a little more up front, project owners can realize significant savings over the long-term.

LCCA is applicable to the utilization of geogrid reinforcement 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 of the Spectra® System 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 comparing it to the present worth of costs (PWOC) of typical maintenance (i.e., chip seal, crack filling) and rehabilitation (asphalt overlay) intervals.

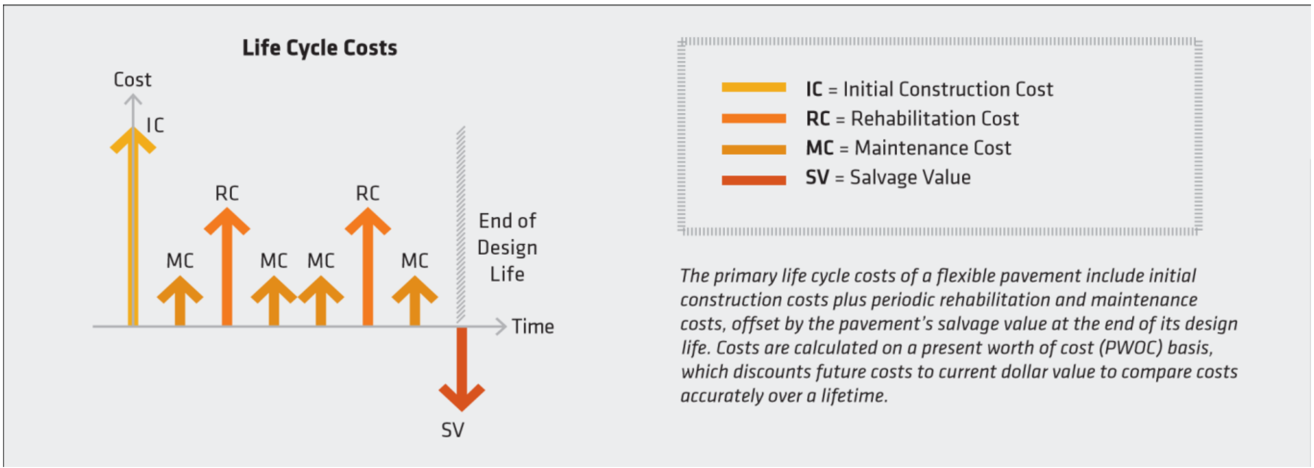
EXAMPLE PROBLEM – LIFE CYCLE COST BENEFITS

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 3 years and rehabilitation every 6 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

Determine the present worth of cost (PWOC) of an unreinforced pavement section compared to an equivalent thickness Spectra System reinforced with Tensar TriAx Geogrid.

SOLUTION:



The primary life cycle costs of a flexible pavement include initial construction costs plus periodic rehabilitation and maintenance costs, offset by the pavement's salvage value at the end of its design life. Costs are calculated on a present worth of cost (PWOC) basis, which discounts future costs to current dollar value to compare costs accurately over a lifetime.

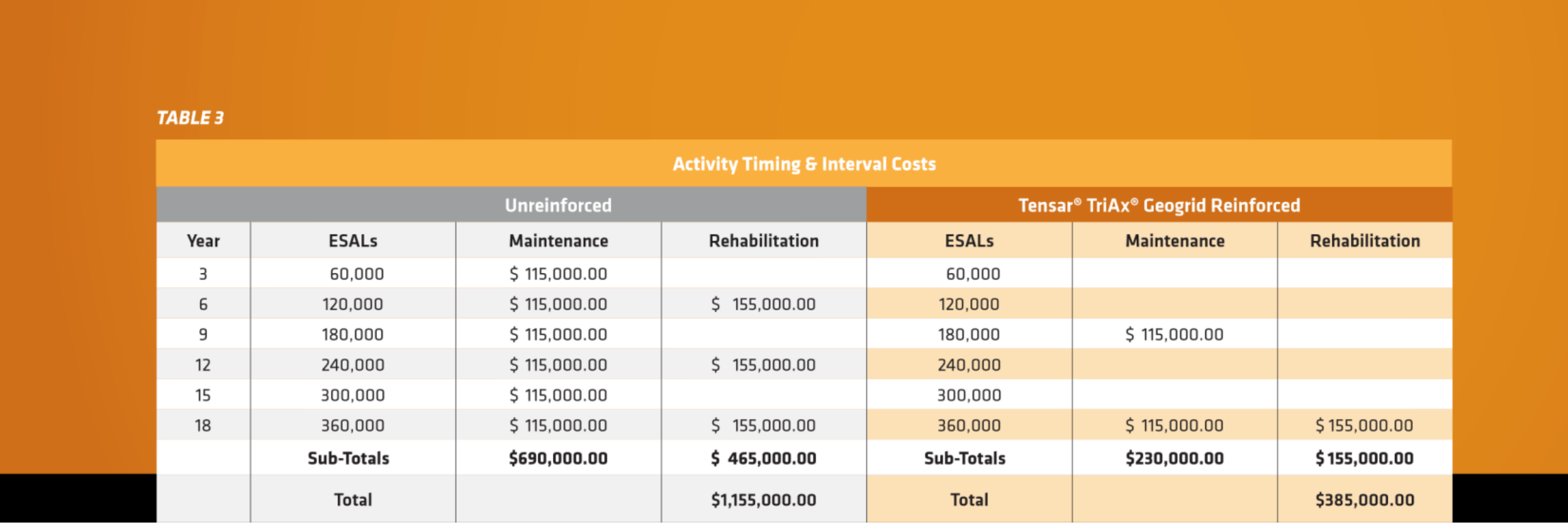


TABLE 3

Activity Timing & Interval Costs						
	Unreinforced			Tensar® TriAx® Geogrid Reinforced		
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**

Step 1: Establish Design Alternatives and Initial Construction Costs

The AASHTO 1993 design method component thicknesses of the unreinforced pavement section and the Spectra® System reinforced with Tensar® TriAx® Geogrid are shown below:

	Unreinforced	Spectra System
Asphalt:	4 inches	4 inches
Aggregate Base:	8 inches	8 inches
Design ESALs:	425,000	1,829,000
Initial Cost:	$533,000	$597,000

Step 2: Determine Activity Timing and Internal Costs

The maintenance and rehabilitation intervals for the Spectra System 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 rule (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).

Discount Factor = $1 / (1 + r)^n$

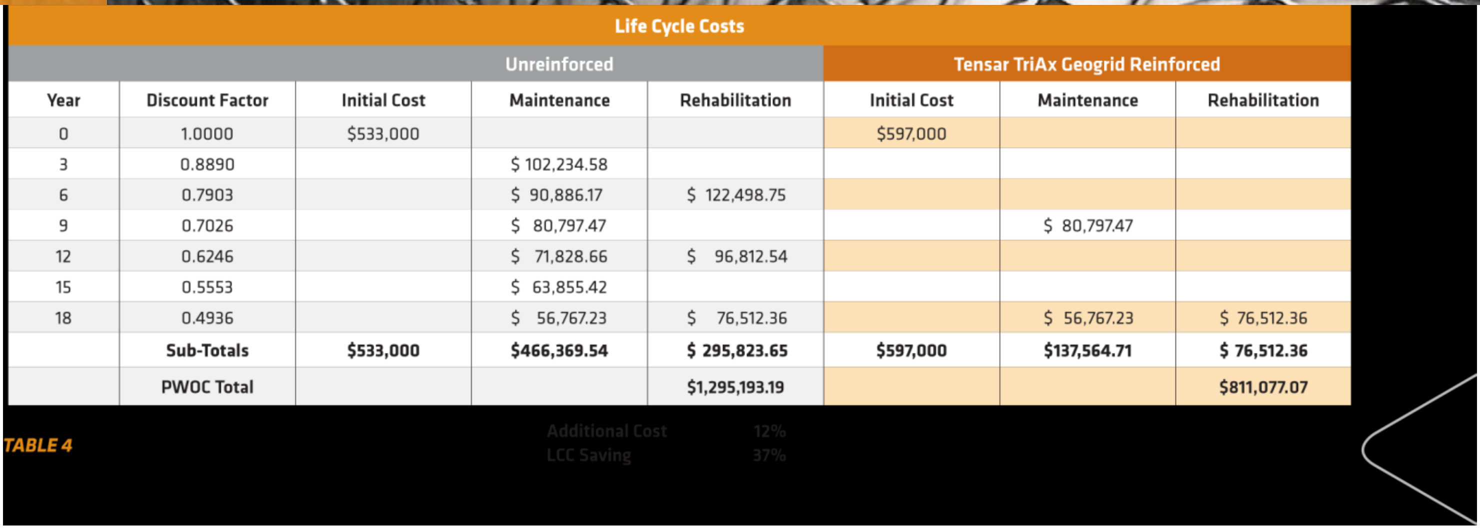
where:

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 the Spectra System with Tensar TriAx Geogrid results in a 12% higher initial cost to the owner at the time of construction, the life cycle cost saving is an amazing 37% lower than for an unreinforced pavement section.



Life Cycle Costs							
Unreinforced					Tensar TriAx Geogrid Reinforced		
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**

Additional Cost 12%
LCC Saving 37%

TABLE 4

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

Design Tools

SPECTRAPAVE4-PRO™ SOFTWARE

Tensar released the latest version of our industry-leading analysis tool, SpectraPave4-Pro™ Software in early 2010. This new software will allow the user to accurately predict the performance of geogrid reinforced and unreinforced 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, this 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

The Solution that Works Every Time

THE SPECTRA® SYSTEM ADVANTAGE

For more than 25 years industry professionals have been using Tensar® Geogrids to build economical, long-lasting structures. With clear advantages in performance, design and installation, the Spectra System 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 trends.

[1] AASHTO. (2003). *Recommended Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures.* AASHTO Publication PP46-01. American Association of State Highway and Transportation Officials, Washington, D.C.

CBR Improvement of Clayey Soil with Geo-grid Reinforcement

I. INTRODUCTION

Desirable properties of sub-grade are high compressive and shear strength, permanency of strength under all weather and loading conditions, ease and permanency of compaction, ease of drainage and low susceptibility to volume changes and frost action. Since sub-grade soils vary considerably, the interrelationship of texture, density, moisture content and strength of sub-grade materials is complex. are sub-grade, sub-base, base course and hearing course effect of geo-grid reinforcement on maximum dry density (MDD), optimum moisture content (OMC), California Bearing Ratio and E value of sub-grade soils.

In addition, reinforced soils are often treated as composite materials in with reinforcement resisting tensile stress and interacting with soil through friction. Although three is lot of information and experience with geo-synthetic reinforcement of subgrade soils, many pavement failures still occur. These failures may be due to lack of understanding of how these materials influence the engineering properties of sub-grade soils and what is the optimum position of reinforcement. Therefore a compressive laboratory program is required to study strength characteristics of both reinforced and unreinforced sub-grade soils also to investigate their behaviors under cycle leading.

This work describes the beneficial effects of reinforcing the sub-grade layer with a single layer of geo-grid at different positions and thereby determination of optimum position of reinforcement layer. The optimum position was determined based on California Bearing Ratio (CBR value) and unconfined compression tests were conducted to decide the optimum position of geo-grid.

II. LITERATURE SURVEY

The concept of reinforcement is not new. Early civilizations commonly used sun-dried soil bricks as a building material. Somewhere in their experience it became an accepted practice to mix the soil with straw or other fiber available to them to improve the properties (Dean, 1986). Various materials were used in reinforcement of both pavement materials and sub-grade soils. They can vary greatly, either in form (strips, sheets, grids, bars, or fibers), texture (rough or smooth), and relative stiffness (high such as steel or relatively low such as polymeric fabrics), (Donald and Ohashi, 1983). Haas (1985) showed that flexible pavements could be effectively reinforced with the polymer geo-grid.

This involves asphalt thickness savings from 50 mm to 100 mm, or the ability to carry two or three times more traffic loads for equal thicknesses. Nejad and Small (1996) investigated the influence of geogrid reinforcement of the granular base of a flexible pavement constructed on sand. They found that geogrid could significantly decrease the permanent deformation in the pavement by 40% to 70%.

Ling and Liu (2001) carried out some static and dynamic tests on model sections to find out the contribution of geo-synthetic reinforcement to the stiffness and strength of asphalt pavements. The reinforcement layer (geo-grid) was laid above the sub-grade and a final layer of asphalt concrete was placed. The study showed that the settlement over the loading area of reinforced pavement was reduced when compared with un-reinforced pavement.

Srinivas Rao, B. and Jagloxshmi S (2008), carried out effect of fiber reinforcement of soil sub-grade beneath flexible pavements, in this work the study on strengthening of soil sub-grade with polymer reinforcement was carried out. The CBR test was carried out without fiber reinforcement. The CBR value of soil without fiber is 3.3%. After addition of fiber reaction the high CBR value was achieved.

Professor Stelin, V.K., Prof. Ravi, E. and Arun Murugen, R.B.(in 2010) carried out the experiment on shrink Behavior of expensive clay using geosynthetics. In this paper attempt is made to control the expansion on swelling clays with geo-synthetics. Swelling tests were conducted on expensive clay with varying orientation and number of layers of geo-grid, geo-membrane and geo-textile and they found the result that the load carrying capacity of swollen clay with geo-grid is high.

Raju, N. Ramakrishna (2010) reported that the usage of geo-synthetics in earth dams and embankments to provide additional stability. Reinforcement of embankment/filling on soft soil reduces construction material quantities, reduces land acquisition and reduces construction time.

III. EXPERIMENTAL PROGRAMME

Material selection: One type of clayey soil was selected for this study. The index properties: liquid limit, plastic limit and plasticity index were determined. Important physical properties and classification of soil are given in table no. 1.

TABLE 1
PHYSICAL PROPERTIES AND CLASSIFICATIONS OF SOIL

Property	Soil
Dry Density (gm/cc)	1.70
Optimum Moisture Content (OMC) %	16.0
Specific gravity	2.60
Coefficient of uniformity (Cu)	8
Coefficient of curvature (Cc)	0.18
Liquid Limit(%)	28
Plastic Limit (%)	15
Plasticity Index	13
Unified classification	CL- Clay of low compressibility

One type of geo-grid was used to reinforce the subgrade soil. Various properties of geo-grid considered for this study are given in table 2.

TABLE 2
PROPERTIES OF GEO-GRID

Property	Grid
Mesh aperture size(nominal) mm	22 x 22
Tensile strength in longitudinal direction at 2% strain (kN/m)	5.8
Stiffness in longitudinal direction (kN/m)	290
Elongation in machine direction	16.5%
Tensile strength in transverse direction at 2% strain (kN/m)	5.2
Stiffness in transverse direction (kN/m)	260
Elongation in transverse direction	10%

A. California bearing ratio (CBR) test

CBR tests were conducted on selected soil, unreinforced and reinforced with a single layer of geo-grid. To reinforce a sample, the geo-grid was placed in a single layer at different positions: 20%, 40%, 60% and 80% of the specimen height from the top surface. It was cut in the form of circular disc of diameter slightly less than that of the specimen to avoid separation in the specimen by the reinforcing layer. The dry weight required for filling the mould was calculated based upon the maximum dry density (MDD) and corresponding optimum moisture content was achieved from standard proctor test. A total of five samples of unreinforced and reinforced type were tested after soaking in water for four days. The load penetration curve was drawn for the soil samples with geo-grid at different positions and the CBR values were calculated from these curves. Table 3 shows the results of CBR tests under different test conditions. It is clear that considerable amount of increase in CBR value of soil with geo-grid reinforcement, for example, in case of unreinforced soil the CBR value is 2.9% and with geo-grid reinforcement the CBR value increases to 9.4%. The highest increase in the CBR value was achieved when geo-grid was placed at 20% depth from the top of the specimen.

TABLE 3

RESULTS OF CBR TESTS FOR DIFFERENT POSITIONS OF GEO-GRIDS

Sr. No.	Position of geo-grid from top of specimen	Unsoaked CBR	Soaked CBR
1.	No geo-grid	6.5	2.9
2.	0.2H	16.05	9.4
3.	0.4H	13.86	7.2
4.	0.6H	10.9	5.8
5.	0.8H	7.2	3.16

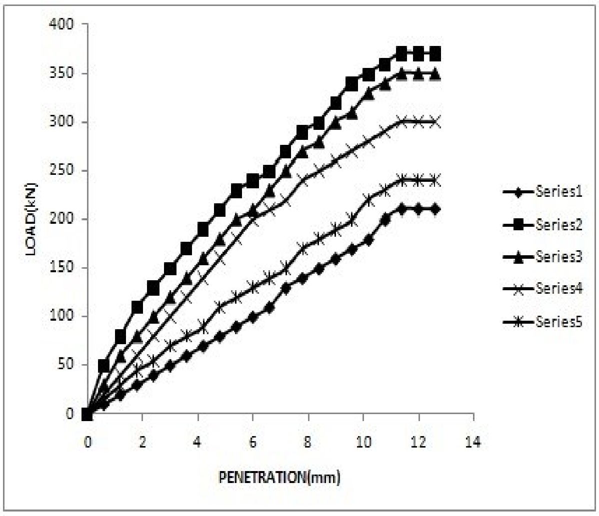


FIGURE 1 LOAD V/S PENETRATION CURVE

IV. CONCLUSIONS

In the present study, reinforced benefits of different layers of a flexible pavement are evaluated in terms of their strength parameters like, CBR and E-value and the important findings of this research are summarized below:

1. The CBR of a soil increases by 50-100% when it is reinforced with a single layer of geo-grid. The amount of improvement depends upon the type of soil and position of geo-grid.
2. CBR of sub-grade soil is 3.6% without reinforcement and when geo-grid was placed at 0.2H from the top, The CBR value increased to 8.7%.

Source: U.S. Army Corps of Engineers ETL 1110-1-189

3. The stress-strain behaviour of sub-grade soils under static load condition improved considerably when geo-grid was provided at optimum position.

Effect of Geogrid Reinforcement Location in Paved Road Improvement

ABSTRACT

A series of two-dimensional finite element simulations are carried out to evaluate the benefits of integrating a high modulus geogrid in a paved road. This paper describes the behavior of reinforced asphalt concrete (AC) pavement under plane strain conditions and subjected to monotonic loading. The results of improvement of paved track using geogrids are presented. Geogrid reinforcement into paved road in most cases will improve the performance of the transportation support. Analytical results for three different most possibilities of geogrid reinforcement in the paved road layers have been evaluated. The optimum position was decided based upon the tension stress absorption value, deformation reduce rate and tension cut-off point location. Three types of reinforcing model and one type of unreinforced model of paved road were selected. The results showed that tension stress absorption increases with shifting the geogrid towards the top of the pavement and attains the highest values when the geogrid is placed between asphalt layer and base layer in model.

KEYWORDS: Paved road, Geogrid, Optimal location, Tension stress absorption.

INTRODUCTION

Geosynthetic materials have been successfully used to stabilize subgrade soils in road construction, which leads to improved performance of paved and unpaved roads. The research conducted so far indicates that the geogrids perform better as a reinforcing element. Reinforced soils are often treated as a composite material, in which the reinforcement resists tensile stresses and interacts with soil through friction. Geogrids can improve the performance of the subgrade soil through four mechanisms: prevention of local shearing of the subgrade, improvement of load distribution through the base course, reduction or reorientation of shear stresses on the subgrade, and tensioned membrane effect. Placed between the subgrade and base course, or within the base course, the geosynthetic improves the performance of paved roads. Reinforcement increases the bearing capacity of the subgrade, stiffens the base layer thereby reducing normal stresses and changing the magnitude and orientation of shear stresses on the subgrade in the loaded area, restricts lateral movement of the base course material and the subgrade soil, and can provide tensioned membrane support where deep rutting occurs (Giroud et al., 1985).

One of the beneficial effects of geosynthetic reinforcement at the interface between base course and subgrade soil is to carry the shear stresses induced by vehicular loads at the interface (Milligan and Love, 1984; Perkins, 1999). The interlocking between the geogrid and the base course aggregate results in reduced lateral movement of the base course aggregate as a result, no outward shear stresses are transmitted to the subgrade. At the same time, the bottom surface of the base course, with confined aggregate striking through geogrid apertures, provides a rough surface that resists lateral movement by the subgrade and increase the subgrade bearing capacity.

The geogrids have an elastic-plastic behavior so that they quickly react to applied loads with an increase in the elastic modulus; in the case of short term impact loading, creep phenomenon does not occur, therefore the whole tensile resistance of the geogrid can be mobilized. Further, geogrids allow an increase of the dynamic dumping characteristics of the reinforced soil compared to unreinforced soil, both through the energy that is directly absorbed

Source: U.S. Army Corps of Engineers ETL 1110-1-189

by the geogrid itself and due to friction generated in the dynamic stage (Carotti and Rimoldi, 1998).

Although there is a lot of information and experience with geosynthetic reinforcement of subgrade soils, many pavement failures still occur. These failures may be due to the lack of understanding of how these materials influence the engineering properties of subgrade soils and what is the optimum position of reinforcement within a layer to derive maximum benefit.

Tension stress absorption of geogrid has changed surprisingly with change in position of the reinforcement. Some researchers believe that geogrid should be placed near the load (Chan et al., 1989), while others have found that it should be near the bottom or at mid-height (Broms, 1977). Giroud et al. (1985) showed that the geogrids could improve the performance of subgrade soil through three mechanisms, namely: confinement, improved load distribution through the base layer, and tensioned membrane effect, which reduces stresses. For pavements constructed on soft subgrades, the reinforcement should be placed at or near the bottom of the base.

Barksdale *et al.* (1989) utilized the results of a 2D finite element method to estimate the reduction in base thickness for a stiff geosynthetic. Miura et al. (1990) carried out an isotropic linear elastic FE analysis using 2D continuum elements to represent the HMA, base, subbase and subgrade layers. Dondi (1994) performed a 3D FE analysis of a pavement structure using non-linear constitutive models for the base and subgrade and a linear elastic model for the HMA and geogrid layers. Wathugala *et al.* (1996) used the ABAQUS finite element program to explore the decrease in the rut depth as a result of placing the geosynthetic membrane at the base–subgrade interface of a flexible pavement system. A series of finite element simulations are carried out to evaluate the benefits of integrating a high modulus geosynthetic into the pavement foundation. Three locations of the geosynthetic reinforcement are studied, namely the base–asphalt concrete interface, the base–subgrade interface, and inside the base layer at a height of 1/3 of its thickness from the bottom. It is found that placing the geosynthetic reinforcement at the base–asphalt concrete interface leads to the highest reduction of the fatigue strain (46–48%).

All these findings indicate that the position of geogrid in a layer is still a subject for research. The present study was undertaken to investigate the optimum position of the geogrid in a layer of sand subgrade soil. The geogrid was placed at different positions and effectiveness of reinforcement layer was investigated through analytical modeling (Plaxis).

FINITE ELEMENT ANALYSIS

An axisymmetric analysis was carried out using Mohr-Coulomb's criterion. The parameters required for all the materials are for the calculations are presented in Table 1. The typical finite element mesh consisted of 1765 nodes and 752 15-node triangular elements. Geogrid has been used as a strain absorption interlayer system. Perkins (2001) demonstrated that in most of these analyses the geosynthetic reinforcement membrane is considered as an isotropic elastic material. Interface elements have been used at the interface of the geogrid. This will allow the relative deformation between the geogrid and gravel and sand layers. Conventional kinematic boundary conditions are adopted, i.e., roller support on all four vertical boundaries of the mesh and fixed support at the bottom of the mesh. Such boundary conditions have been successfully used by Kuo *et al.* (1995). Iterative procedure is adopted for the solution to reduce the normal out of balance force. This strain absorption interlayer system is a soft layer that is usually placed at the bottom of an HMA overlay to absorb a large portion of the energy.

The unreinforced structure was modeled for a loading of 557 kPa having a radius of 200 mm (Yoder and Witczak, 1975; Hansen *et al.*, 1989). The analysis was carried out for drained condition without pore water pressure changes. To simulate the stress dependency of the moduli, the structural layers were divided into sub-layers with the same strength parameters, but different moduli. The axisymmetric analysis was used to get a three dimensional stress distribution. The use of plain strain analysis, where the loading would have been continuous line loading, would have given an overestimation of the stresses and responses.

Table 1: Input parameters.

Material	Asphalt	Crushed Rock	Crushed Gravel	Sand
Thickness (mm)	50	200	250	1500
Elastic modulus (MPa)	5400	300-220-200	140-90	75
Poisson's ratio	0.3	0.35	0.35	0.35
Unit weight (kN/m^3)	25	21.2	22	18
Cohesion (kPa)	-	30	20	8
Friction angle (°)	-	43	44	36
Dilatation angle (°)	-	13	14	6
K_0	1	0.32	0.3	0.42

To model the surface load of the dual wheel, the total load was transferred to a circular loading with an average contact pressure (Korkiala *et al.*, 2003) as shown in Figure 1.

Source: U.S. Army Corps of Engineers ETL 1110-1-189

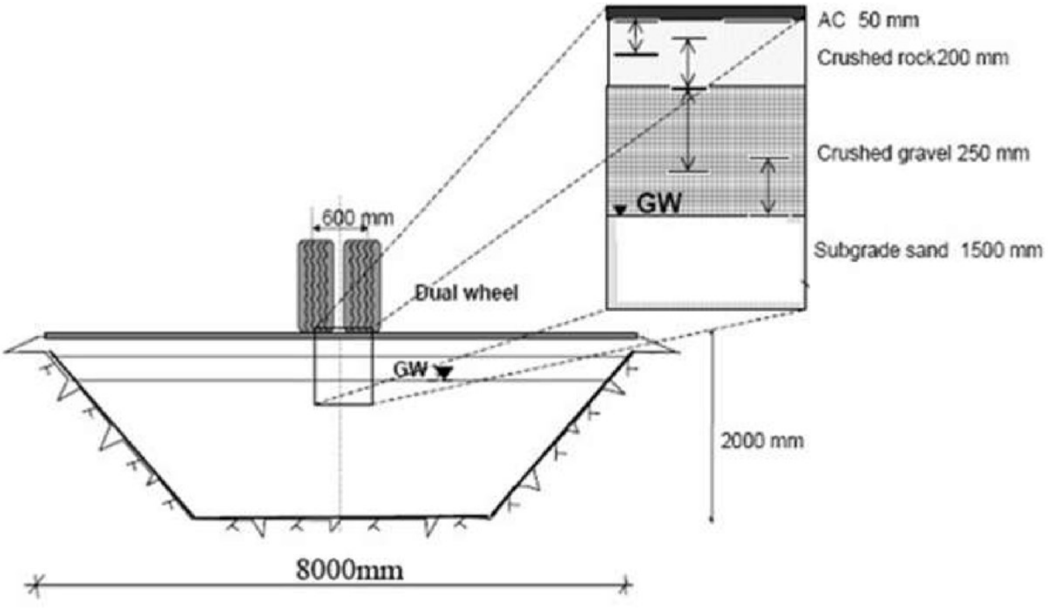


Figure 1: Element surface load of the dual wheel.

The deformation modulus of unbound material is usually strongly dependent on the stress state. The base and subbase layer were divided into thinner layers with the same strength parameters but with different modulus values. The modeling was carried out with the parameters adopted from the standard (ASTM D11241–94). The element mesh and boundary conditions of the unreinforced structure are shown in Figure 2.

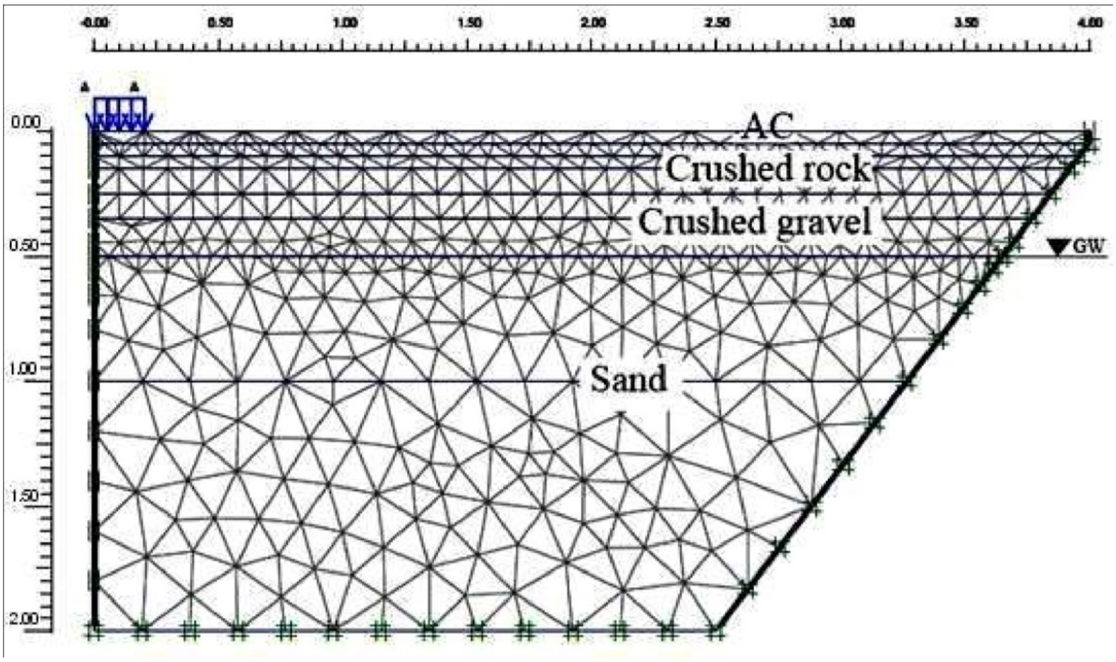


Figure 2: Element mesh and boundary conditions of the unreinforced model.

In these models, the attention was paid to the stress distributions and to the resilient deformations. All analyses carried out were static. The dynamic analysis was not carried out because the dynamic module of the Plaxis program is not suitable for modeling of traffic loading (Korkiala et al., 2003).

The reinforced structure was modeled with the same properties of unreinforced model but geogrid reinforcement placed in three different locations to study the effect of geogrid location in tension stress absorption. To start with, the geogrid was placed under the asphalt layer (Y = 0.05 m), under the base layer (Y = 0.25 m) and finally located under sub-base layer (Y = 0.5 m). The element mesh and boundary conditions of the reinforced structure are shown in Figure 3.

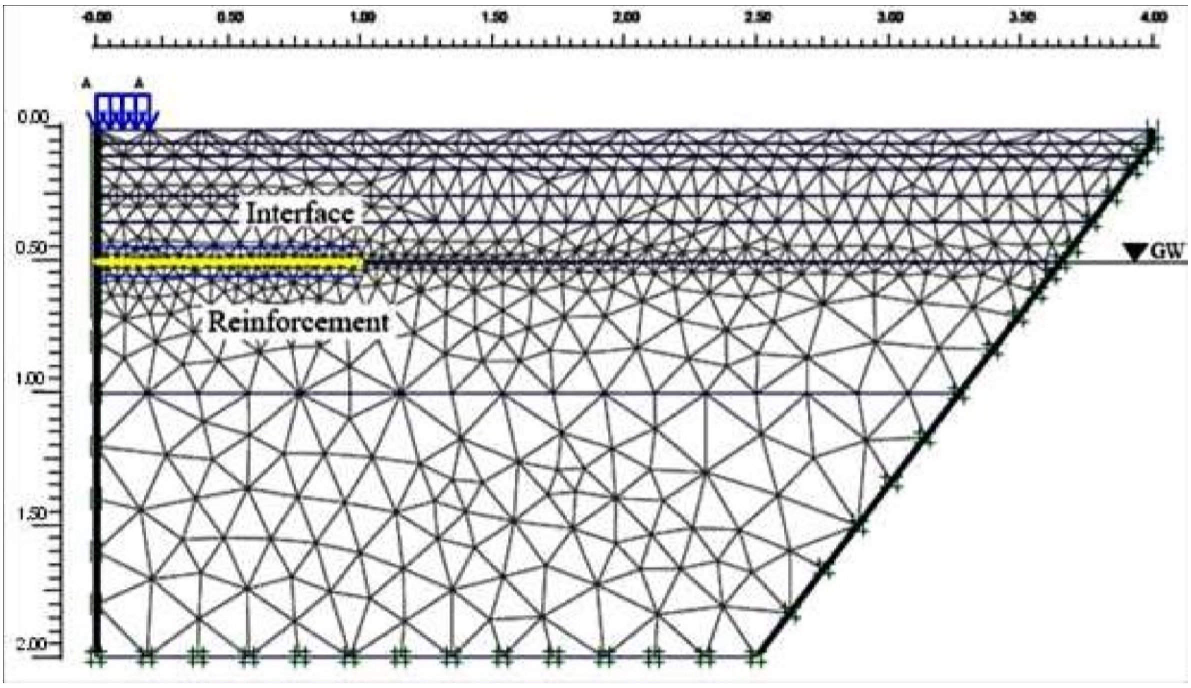


Figure 3: Element mesh and boundary conditions of reinforced model (Y = 0.5 m).

REINFORCEMENT PROPERTIES

The various properties of geogrid are shown in Table 2.

Table 2: Properties of geogrid.

Parameters	
Geogrid type	BX-1100
Polymer	Polypropylene

Source: U.S. Army Corps of Engineers ETL 1110-1-189

Aperture shape	Rectangle
Aperture size (MD/XD)(mm)	25/33
Rib thickness (mm)	0.75
Junction thickness(mm)	2.8
Tensile strength at 5% strain (kN/m)	
MD	8.46
XD	13.42
Initial modulus (kN/m^2)	
MD	226.4
XD	360.1
Long term allowable strength in crushed aggregate	
MD	N/A
MD = machine direction	
XD = cross machine direction	

RESULTS AND DISCUSSION

The results of the modeling are presented in Figures 4 to 11. Figure 4 shows the variation of the shear stress in interface with distance from the load for geogrids placed at various locations. The maximum shear stress in the interface is 21.5 kpa for geogrid placed at a distance of 0.5 m from the bottom of the model, 57.3 kPa at 0.25 m and 157.4 kPa at 0.05 m. It was clear that the geogrid placed at the bottom of asphalt layer (Y = 0.5 m) has increased surprisingly the shear stress in the interface (Barksdale et al., 1989; Ling and Liu, 2003). These stresses will be transferred to geogrid as tension stress.

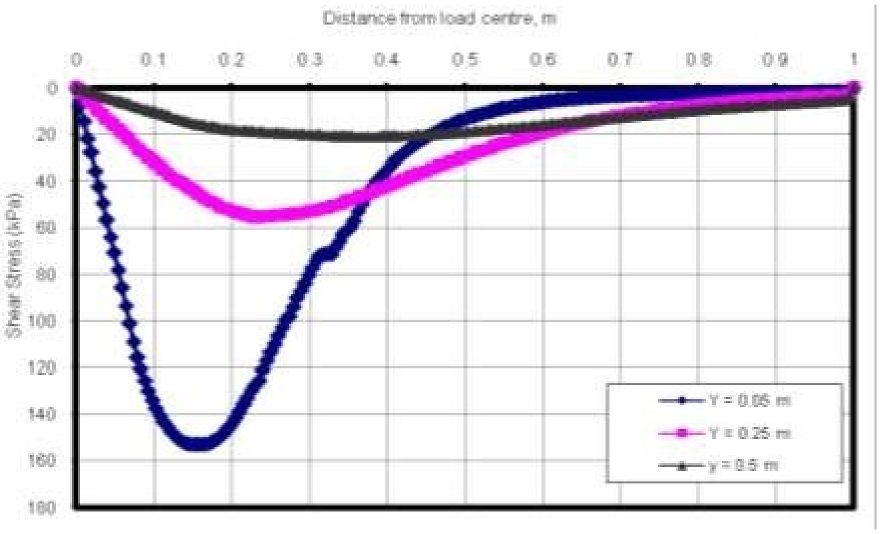


Figure 4: Effect of different locations of geogrid on shear stress absorption of shear interface).

The variation of effective normal stress in shear interface of soil-geogrid from the load is shown in Figure 5. The effective normal stress for the geogrid place at 0.5 m from the base of the model is 84 kPa, 190 kPa at 0.25 m and 460 kPa at 0.05 m. High normal stresses on the center of loading can produce high shear stresses at shear interface as shown in Figure 4.

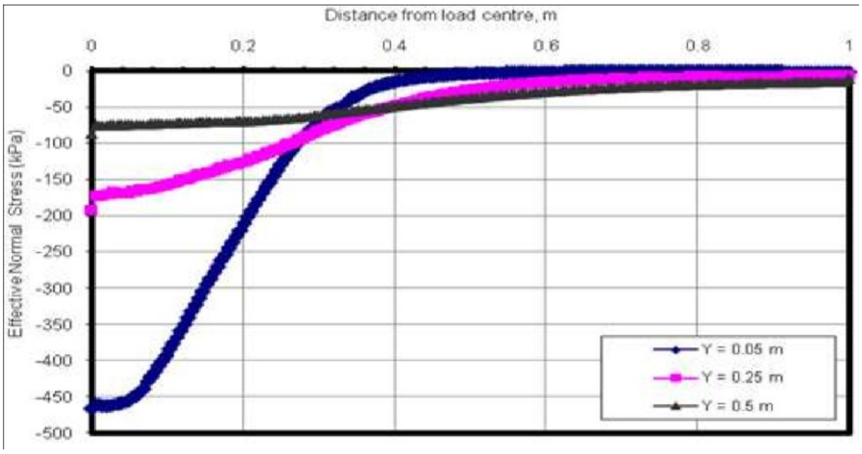


Figure 5: Effect of location of geogrid on normal stress at the interface.

The vertical deflection of geogrids with distance from the load is shown in Figure 6. The deflection observed under the centre of the load for unreinforced model is 1.16 mm and this reduces to 0.0019 mm with the use of geogrid just under the asphalt layer.. This shows the effectiveness of geogrid in controlling the deflection when used just below the asphalt layer.

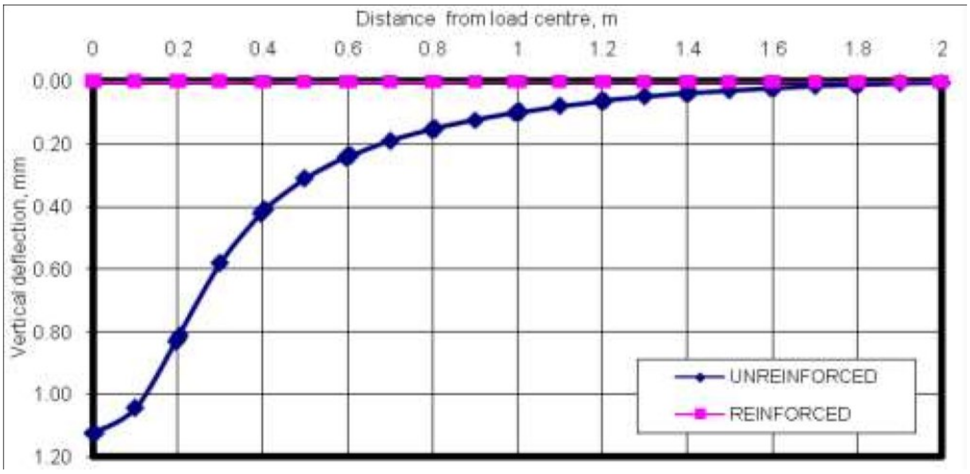


Figure 6: Vertical deflections for unreinforced and reinforced model.

Source: U.S. Army Corps of Engineers ETL 1110-1-189

In Figure 7, the results of vertical deflection of the geogrids for three locations of the reinforcement are presented as a comparison to find out the location which gives the least vertical deflection. The results were quiet surprising because it showed very identical deflections.

The deflections were about 0.0019 mm under the center of the load and decreasing sharply to about 0.0001 mm at 0.3 m from the center of the load. However, there were differences in tension absorption. In fact these analyses are valid only for the cases where permanent strains during one loading cycle are an insignificant part of resilient strains.

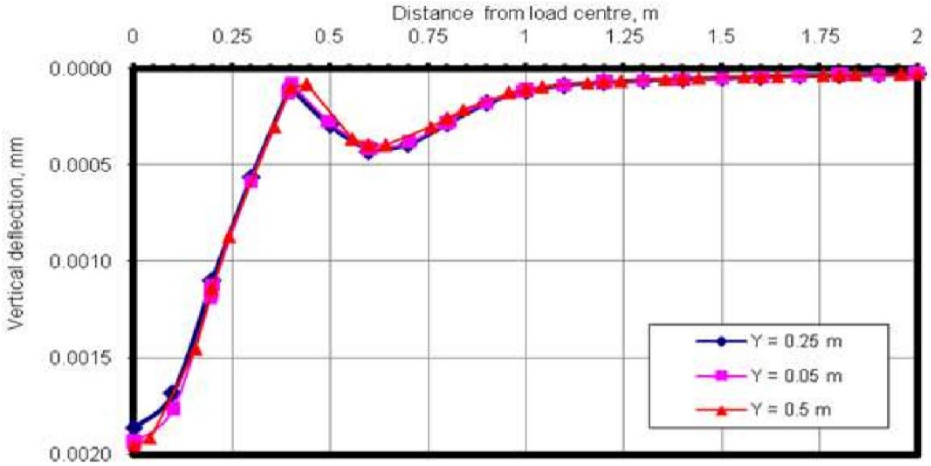


Figure 7: Vertical deflections in model with geogrid at three different locations.

Figures 8 to 11 show the locations of plastic and tension-cut-off points developed in the reinforced and unreinforced models for the same conditions. It was observed that similar results were also seen in Figures 5 and 6. The tension cut-off points in reinforced structure were concentrated close to the reinforcement layers. The magnitude of concentration was observed to increase when using the reinforcements close to the load applied. This indicates that the load applied was taken up by the geogrids. The effectiveness of geogrids is more pronounced when it is placed at the bottom of the asphalt concrete.

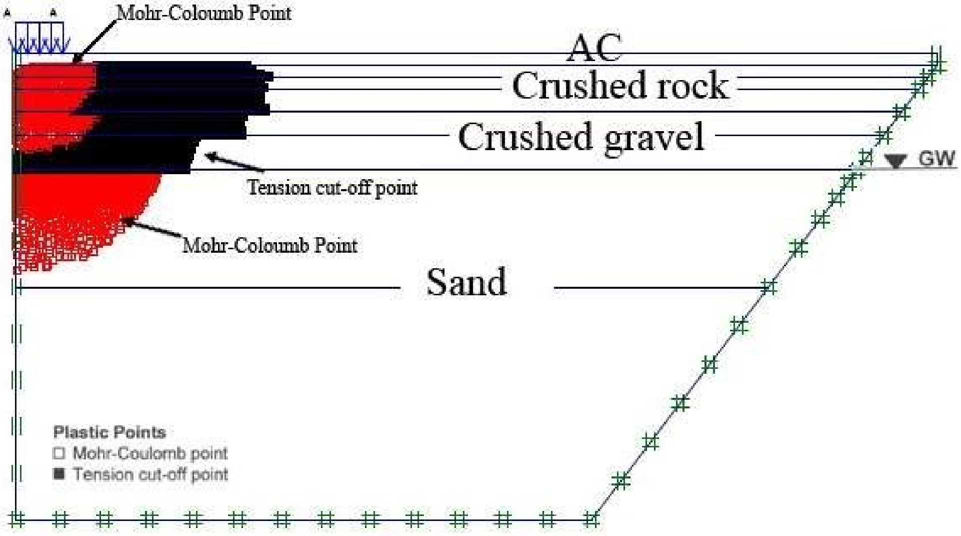


Figure 8: Plastic and tension cutoff points (unreinforced).

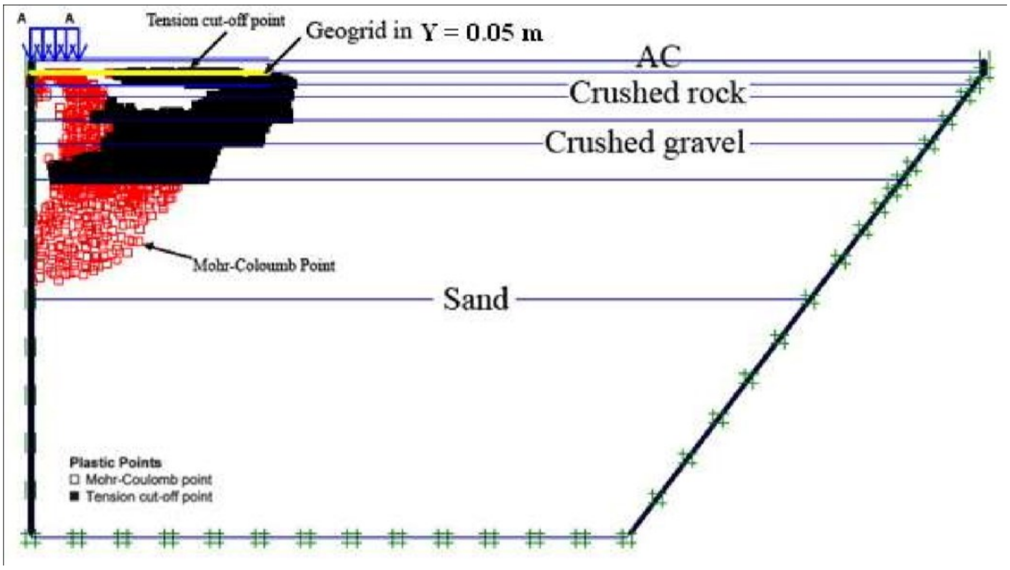


Figure 9: Plastic and tension cut off points (reinforcement at Y = 0.05 m).

Source: U.S. Army Corps of Engineers ETL 1110-1-189

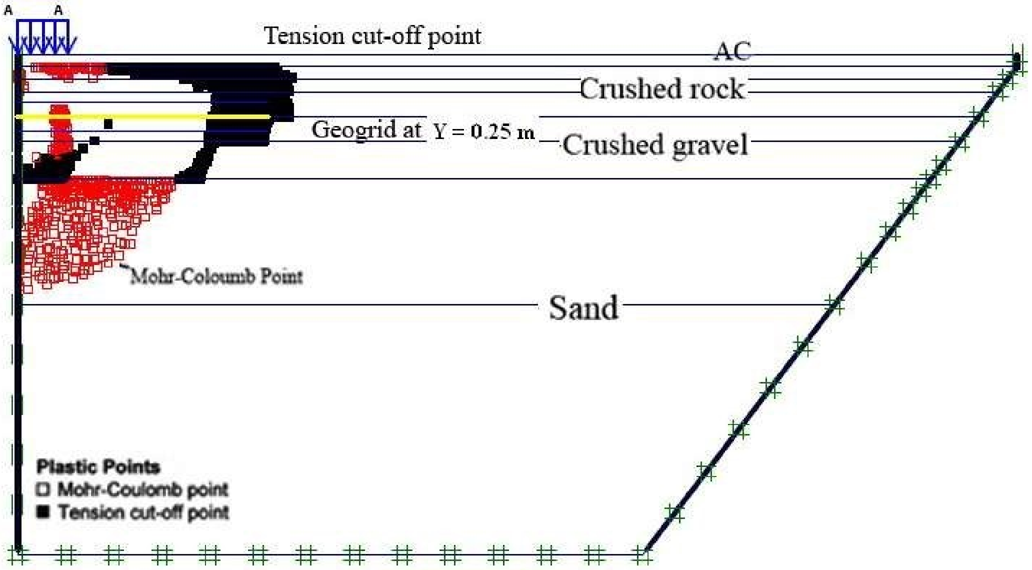


Figure 10: Plastic and tension cut off points (reinforcement at Y = 0.25 m).

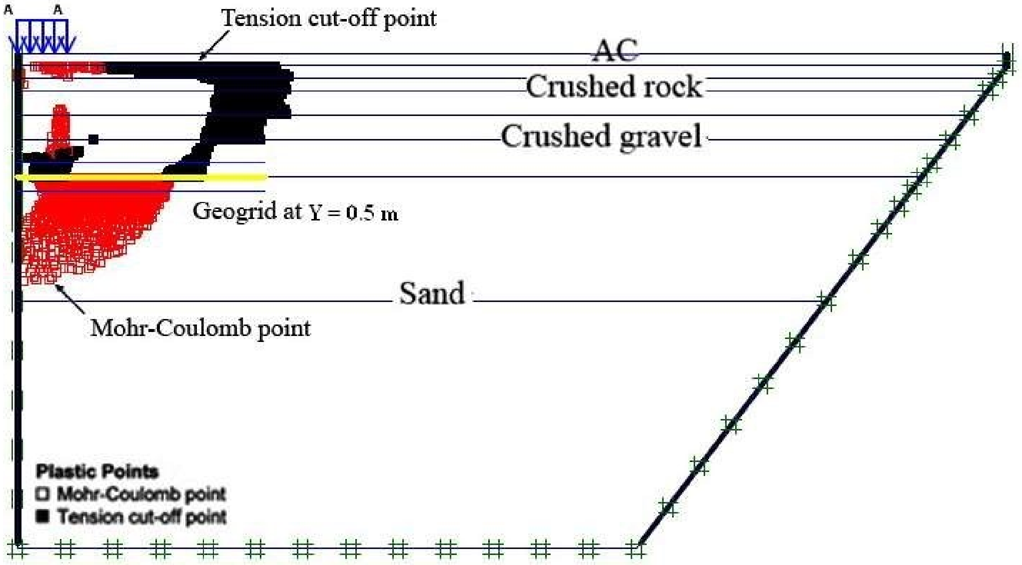


Figure 11: Plastic and tension cut off points (reinforcement at Y = 0. 5 m).

CONCLUSIONS

A finite element representation of geogrid is presented for the analysis of soil-geogrid interaction system. The technique is used in association with a two-dimensional axisymmetric finite element type of analysis to study the behavior of geogrids embedded in paved roads. The results showed the restraining effects of geogrid in the asphalt pavement system. When the load is applied to the surface of the pavement, a zone of tension is developed at the lower section of the asphalt concrete layer. To improve the rigidity of the asphalt concrete layer, which may be considered as a beam, the geogrid is included as tensile reinforcement. The tensile stress acting in the asphalt concrete is thus transferred to the geogrid as tensile force. When the geosynthetic reinforcement is placed at the bottom of the asphalt concrete layer, it leads to the highest reduction in the vertical deflection. The overall performance of the asphalt pavement is improved if an effective bonding is maintained between the asphalt concrete and geogrid. Also, the settlement over the loading area of reinforced pavement reduced when compared with unreinforced

Source: U.S. Army Corps of Engineers ETL 1110-1-189

Geogrid Mechanisms

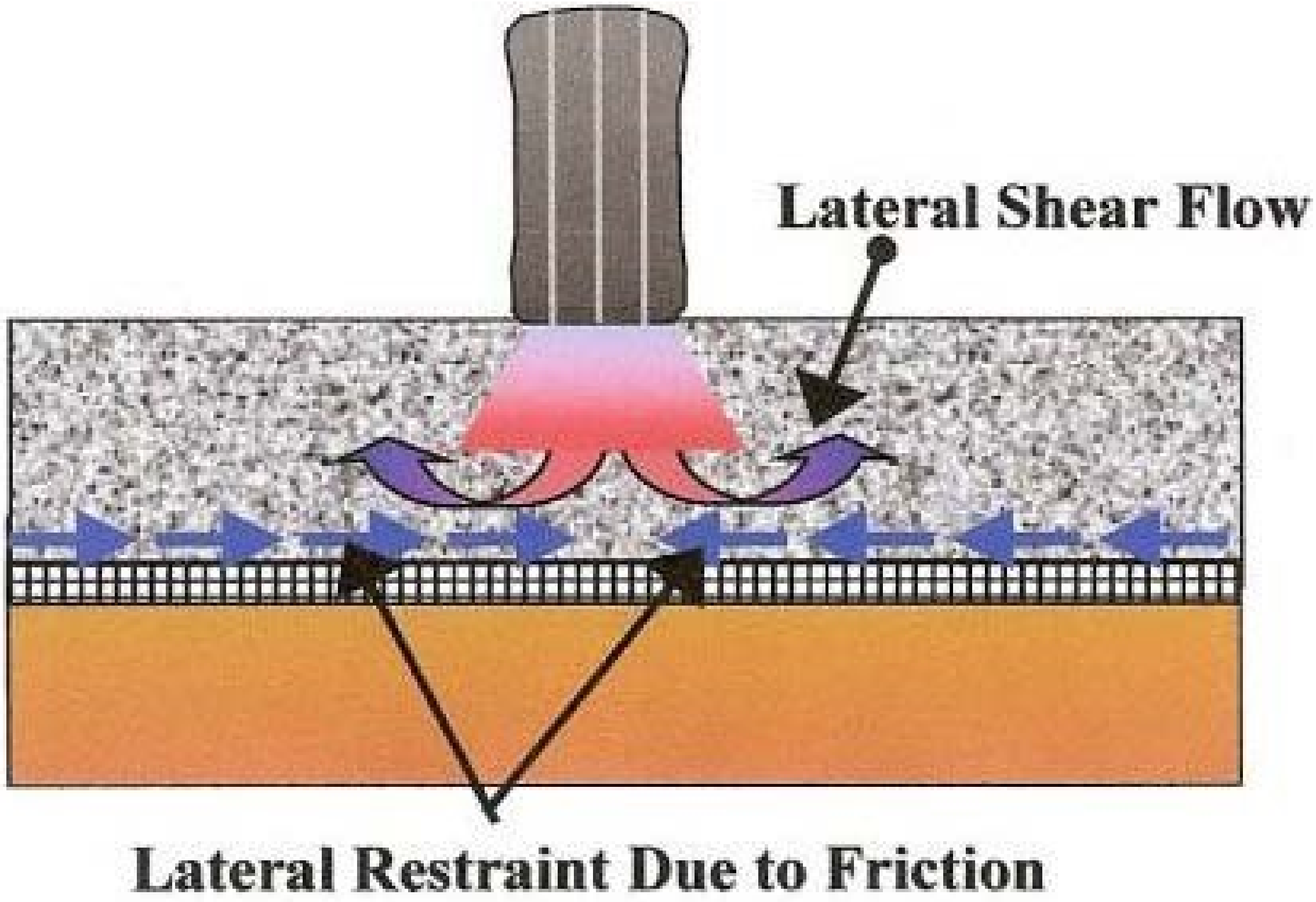


Figure 1. Lateral restraint reinforcement mechanism.

Geogrid Mechanisms -- Why Use Geogrid ?

- Subgrade Improvement

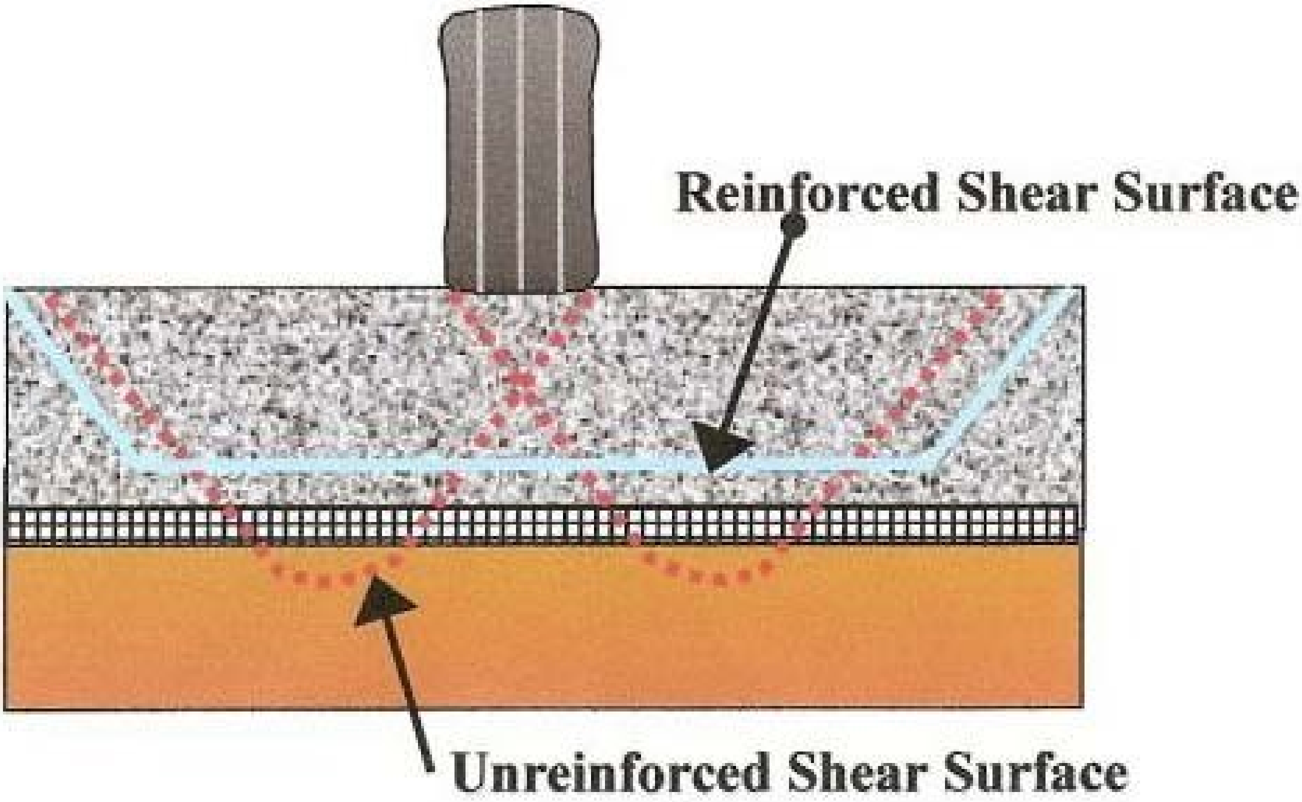
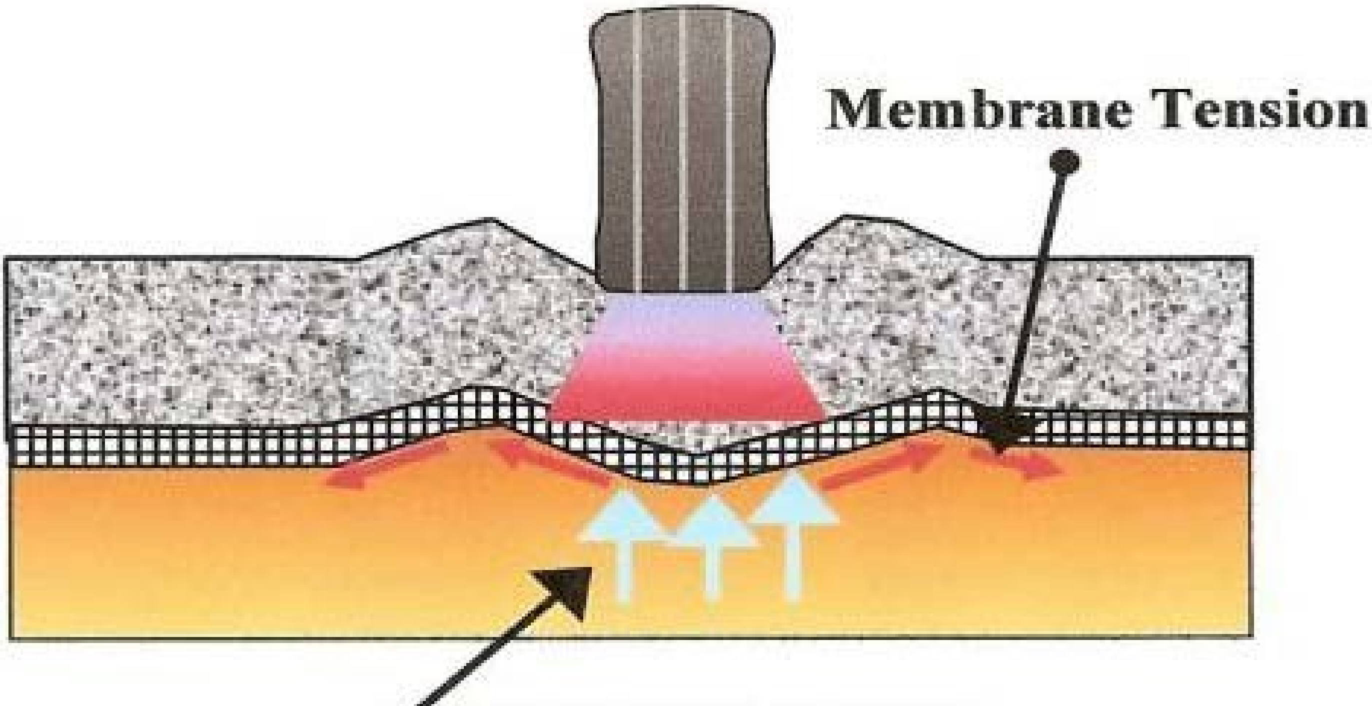


Figure 2. Improved bearing capacity reinforcement mechanism.

- Reduction of undercutting poor soils
- Provides a solid construction platform



  - Protection of soft subgrade soils

- Pavement Base Reinforcement
  - Stiffening aggregate base
  - Reduction in pavement thickness
  - Extended pavement life

General Geogrid Design

- Based on strength (CBR) of existing subgrade and traffic data
- Worked with manufacturer and used their design software to determine our

Salo Road Design Considerations

- 2-mile long Rural Major Collector

proposed pavement structure based o
our soils and traffic data

- ADT 255
- 2% Commercial Traffic
- Soil consisting mainly of sandy organic silts with pockets of “topsoil” and cobble in fill areas.
- Existing 0”-12” of pit run aggregate base under 1.5”-8” of bituminous “road mix”

Source: U.S. Army Corps of Engineers ETL 1110-1-189

Salo Road Design Considerations

- Existing 10′ lanes and 3′ aggregate shoulders
- Existing pavement severely alligatored and rutted
- Unrealistic to undercut all bad subgrade areas
- Didn‘t want to raise the grade due to existing narrow footprint
- Didn‘t want to spend a fortune to fix but didn‘t want to be back in <10 years

Design Considerations

- Had prior experience with biaxial geogrid with good results
- Worked with company representative and utilized their design software to determine our project met minimum cover requirements of 6″ of 22A over the geogrid.

Source: U.S. Army Corps of Engineers ETL 1110-1-189

- Proposed plan was formed

Proposed Project: Phase 1

- Cold mill 8″ of existing HMA, agg base and subbase starting at centerline going outward at 2%
- Contractor grade and roll subgrade prior to placing georgrid (include this in SP)

Proposed Project: Phase 2

- Place geogrid on subbase
- Rolls were 13.1′ wide x 246′ long
- Contractor would roll them out and overlap at least 1′ on centerline and on the ends (overlap depends on subgrade strength)

Source: U.S. Army Corps of Engineers ETL 1110-1-189

- Use zip ties as needed to hold down
- Trial and error to find what worked best

- Found that keeping roll close to gravel seemed to work best

Proposed Project: Phase 3

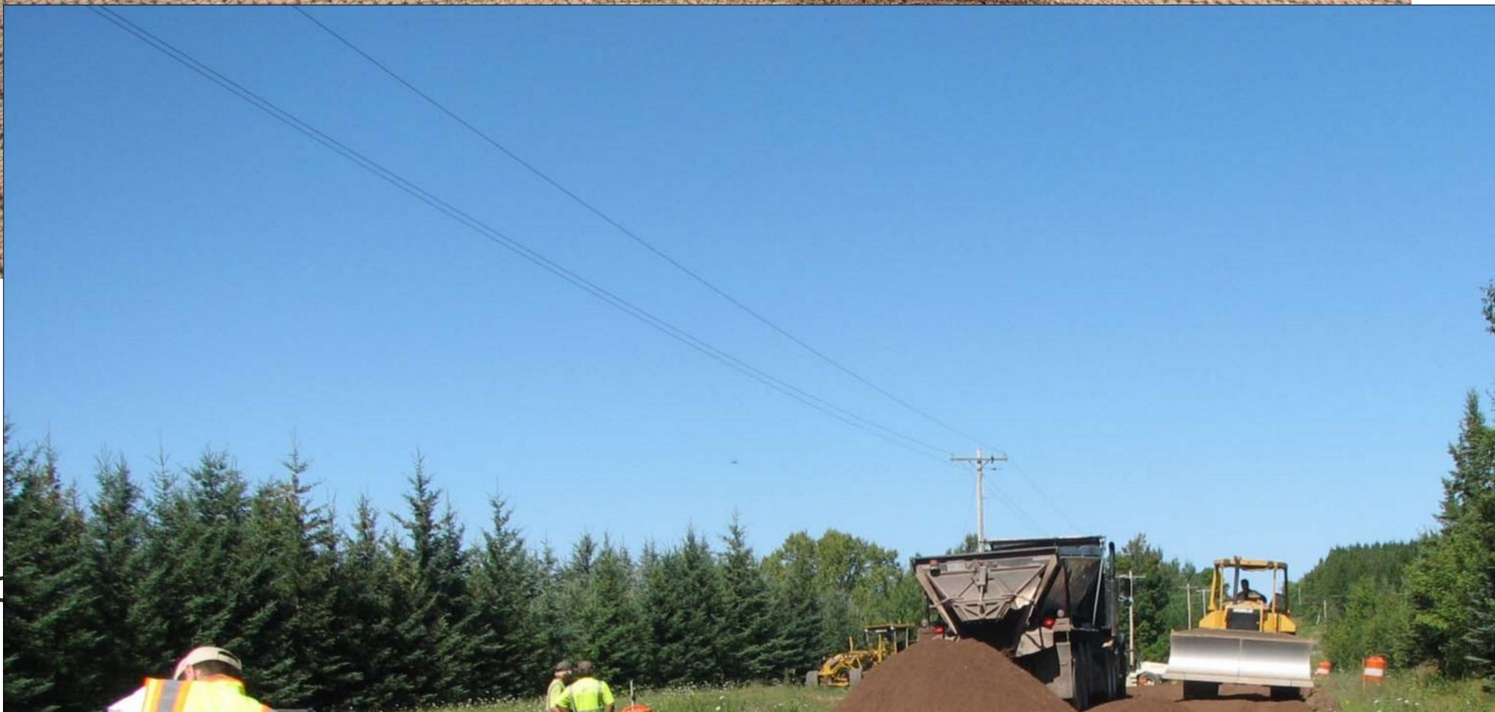
- Placing 6" of 22A on the geogrid was done by dumping on previously placed aggregate and pushing onto the grid with a dozer
- Dozer operator would start on centerline and push aggregate to the edges

being careful to cover the centerline overlap in the correct direction

- Laborer would measure how far each truck load needed to make it based on its weight
- Performed random depth checks to ensure proper aggregate thickness

Source: U.S. Army Corps of Engineers ETL 1110-1-189

Source: U.S. Army Corps of Engineers ETL 1110-1-189



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Source: U.S. Army Corps of Engineers ETL 1110-1-189

Geogrid Information

- Wrote a SP and based acceptance on manufacturer's certification with test results that the product met certain physical properties
- Tensar Triax TX 140 was used on the project

- Unit price was $1.75 per Syd which was about $27,000 per mile for the project

Lessons Learned

- Geogrid won't bridge muck/peat
- Don't run trucks on subgrade if possible
- Make sure dozer is pushing the right way over the centerline overlap
- Make sure the dozer is lifting its blade at the end of the push
- Fold over and crease small waves in the grid and pile aggregate on it to hold it down until it is permanently covered

Lessons Learned

- Set up extra aggregate to touch up areas that are light

Source: U.S. Army Corps of Engineers ETL 1110-1-189

Site Preparation

Clear and grub

- Strip topsoil and other unsuitable material if necessary
- Avoid subgrade disturbance if existing/plan grades allow
- Lightly roll or backdrag to smooth ruts

Placing and Overlapping Geogrid

- Shingle in the direction of fill placement

- Plastic or wire ties may be used to secure overlaps
- These are non-structural, only for ease of construction
- Most helpful on extremely soft subgrades

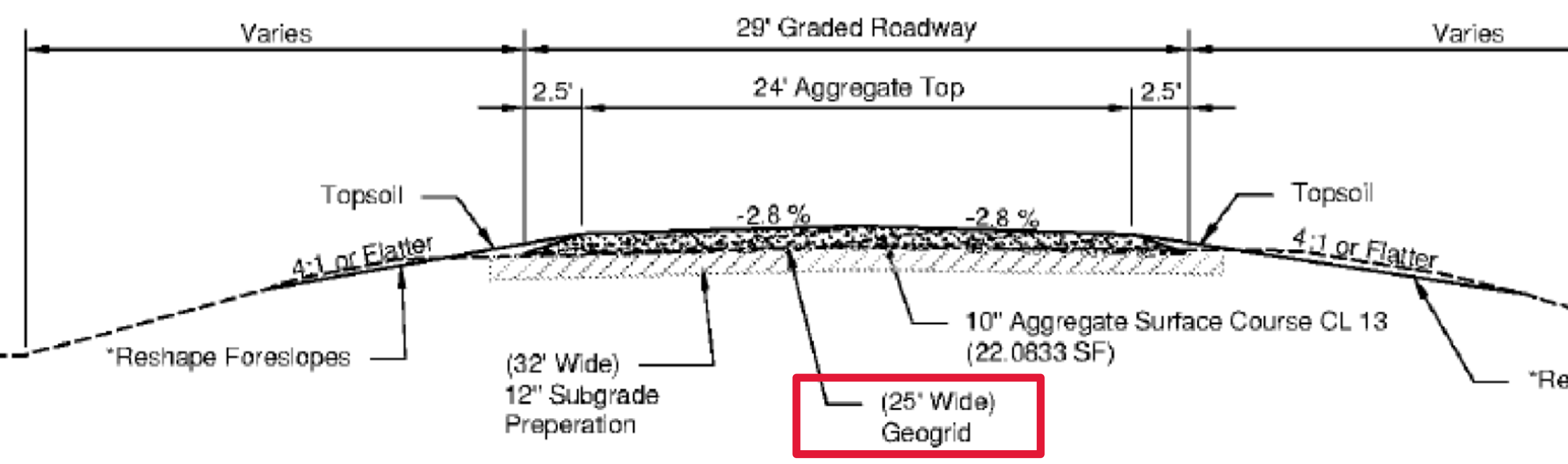
- Geogrid may exhibit "roll memory"
- Pins, staples, or small piles of aggregate may be used to secure
- Not required

Geogrid Overlaps Geogrid Overlaps Fill Placement

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]
CBR ≤ 0.5	N	T or L	3 ft	Y	N
0.5 ≤ CBR ≤ 2	Usually	L	2-3 ft	N	N
2 ≤ CBR ≤ 4	Y	L	1-2 ft	N	Limited
4 ≤ CBR	Y	L	1 ft	N	N

NOTES:



PROPOSED TYPICAL
STA. 12+04 TO STA. 278+82

- 6” minimum compacted thickness recommended
- 8” recommended for CL5 / CL13 subjected to traffic

- Dump at or before edge of exposed geogrid

- Spread with dozer (preferred) or grader

- Rubber tires directly on geogrid is acceptable (avoid turning)

- No tracked equipment directly on geogrid

- Advance fill ahead and to the edges of geogrid

- Some “waving” in geogrid ahead of fill placement is normal
- Excessive pinning and tying can create problems

- Compact using standard equipment and procedures

Spreading Aggregate Spreading Aggregate

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