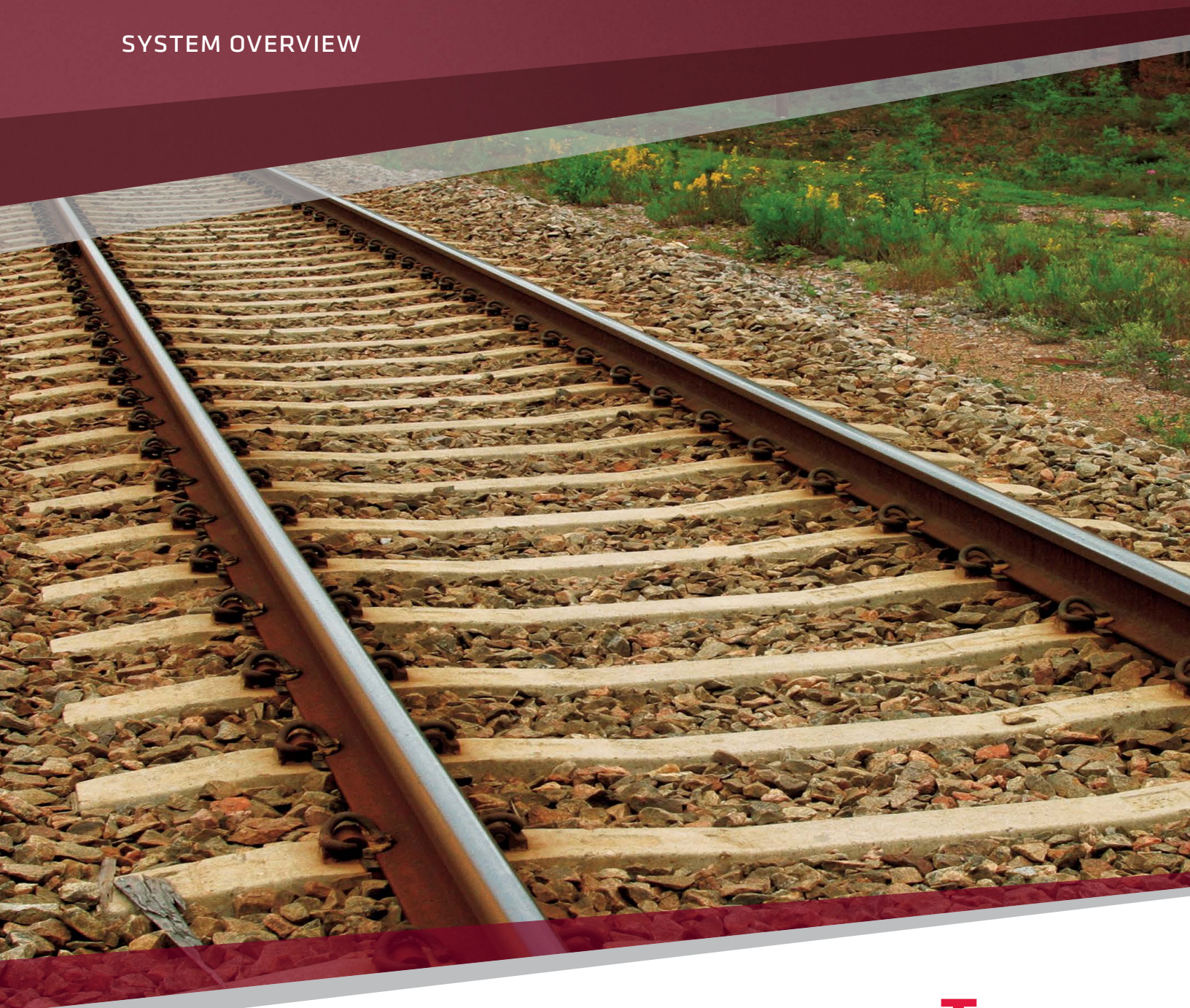
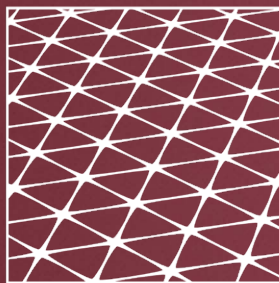


RAILWAY IMPROVEMENT SYSTEM

SYSTEM OVERVIEW



► The Spectra® Rail System provides a predictable, cost-effective solution for the stabilization of ballast and sub-ballast layers.



TENSAR® GEOGRIDS

Tensar® TriAx® Geogrids stand the test of time, performing better than biaxial geogrids due to more effective stress transfer and confinement capabilities. For more information, visit www.tensarcorp.com/triax.

Tensar® TriAx® Geogrid Keeps Rail Performance on Track

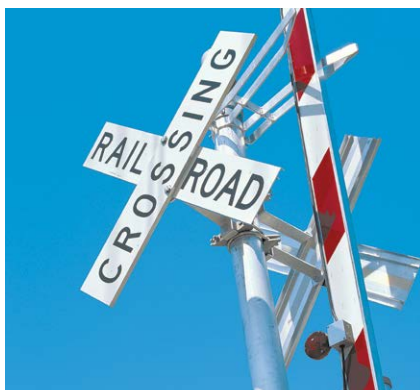
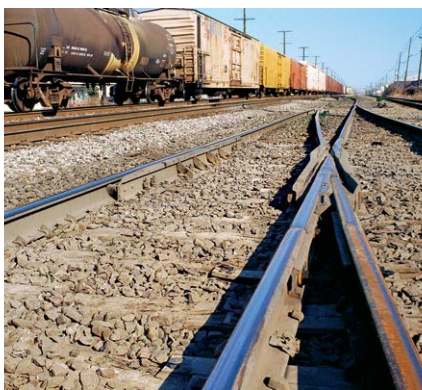
For more than two decades, Tensar® Geogrids have successfully stabilized ballast and sub-ballast layers under a wide range of soil and loading conditions – from light rail to heavy Class 1 rail structures. The American Railway Engineering and Maintenance of Way Association (AREMA), the nation's foremost authority on industry practices, has also recognized the value of geogrid technology for trackbed stabilization by including a chapter on geogrid in its 2010 Manual for Railway Engineering. Indeed, the benefits of using geogrid over soft and firm subgrades have been demonstrated in a number of laboratory and field tests as well as on hundreds of actual installations around the world.

With its unique triangular structure, TriAx Geogrid is the state-of-the-art in geogrid technology. Its multi-directional properties leverage its triangular geometric structure, one of construction's most stable shapes, to provide maximum in-plane stiffness and aggregate confinement. Mechanical stabilization with TriAx Geogrid offers the rail industry a better alternative to conventional materials and practices. As part of the Spectra® Rail System, TriAx Geogrid provides a predictable, cost-effective solution for the stabilization of ballast and sub-ballast layers that includes many advantages:

- Lower up-front construction costs – mechanical stabilization of the sub-ballast layer reduces the

amount of aggregate required to obtain a particular factor of safety against bearing capacity failure. Typically, savings of approximately \$30,000 per linear mile of track can be attained.

- Increase the speed of construction – less aggregate means less construction time.
- Minimize ballast settlement and lateral creep – the period between maintenance cycles can be extended by a factor of three to five times when a TriAx Geogrid is used to stabilize the ballast layer.
- Maintain effective drainage of the roadbed – stiff TriAx Geogrids help prevent aggregate and subgrade soil fouling and reduce the generation of fines through particle abrasion.
- Extend the life of mechanical rail line components (rails, ties, joints, etc.) – less vertical deflection during loading results in less wear and tear in the mechanical components of the rail structure.
- Improve performance and operational productivity by eliminating the need for speed restrictions on potentially troublesome sections of rail line.



The Mechanism of Interlock

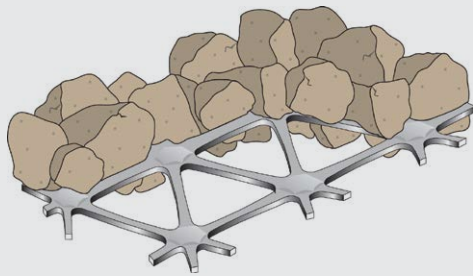


FIGURE 1

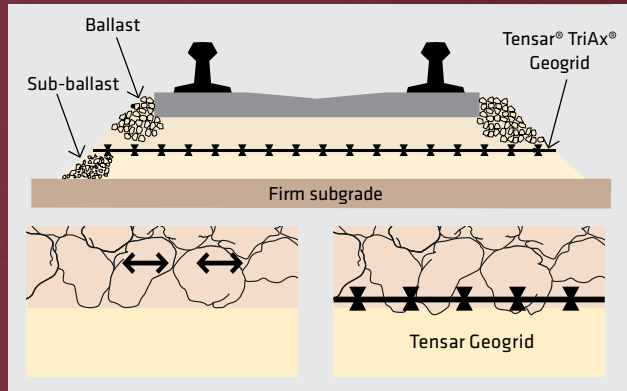


FIGURE 2

How TriAx® Geogrids Work – Mechanical Interlock

APPLICATIONS

Tensor® TriAx® Geogrids stabilize ballast and sub-ballast layers through the principle of mechanical interlock. When unbound aggregate is compacted over a geogrid, the coarser particles partially penetrate through the geogrid apertures and lock into position (Figure 1). As the aggregate layer stiffens, the load distribution over the underlying subgrade is enhanced, increasing its effective bearing capacity.

In addition, the geogrid's ability to confine aggregate particles significantly reduces lateral spreading of granular particles, a major cause of ballast and sub-ballast settlement (Figure 2). TriAx Geogrids offer strength at low strain in all directions, preventing large deformations within the aggregate. The rigid triangular apertures of TriAx Geogrids are designed to interact with typical railroad ballast and sub-ballast materials to ensure optimum mechanical interlock. Geogrids with larger apertures (for example, Tensor® TX190L) are used to stabilize the coarser aggregates typically used for ballast layers.

BALLAST AND SUB-BALLAST STABILIZATION

Tensor TriAx Geogrids are used to stabilize the trackbed structure in two ways:

- ▶ **Sub-ballast Stabilization** – installed at the bottom of the sub-ballast, TriAx Geogrids help distribute imposed loads more efficiently over the underlying subgrade, leading to a reduction in the required sub-ballast layer thickness (Figure 3a).
- ▶ **Ballast Stabilization** – installed between the ballast and sub-ballast layers, TriAx Geogrids limit lateral particle migration and thereby minimize track settlement. This helps increase the period between maintenance cycles by three to five times (Figure 3b).

INTERMODAL FACILITIES

The loads imposed in the loading/unloading paved areas adjoining rail lines at intermodal facilities generally exceed those applied to the trackbeds themselves. These heavy-duty pavement structures are designed to support loads not only from truck traffic, but from cranes and other cargo transfer equipment.

In addition to thousands of successful roadway installations, Tensor® Geogrids have provided stabilization solutions for the pavement structures at many intermodal facilities. Tensor Geogrids at intermodal facilities have been used to:

- ▶ Minimize the required aggregate thickness and the overall cost of pavement structures
- ▶ Increase the speed of construction, reducing labor and equipment costs
- ▶ Reduce or eliminate the need for over-excavation, disposal and replacement of poor quality soils
- ▶ Eliminate the need for lime or cement treatment of the subgrade
- ▶ Integrate industry-leading, technology-based design practices
- ▶ Extend the design life of heavy-duty pavements by a factor of three to six times, leading to significant life cycle cost savings
- ▶ Provide an easily installed, sustainable solution that minimizes construction truck traffic and impact to the surrounding public infrastructure



Tensar® TriAx® Geogrids save on initial and long-term costs

COST BENEFITS

Tensar® TriAx® Geogrids provide both short-term and life cycle cost savings. By significantly reducing the required trackbed thickness (Figure 4), Tensar TriAx Geogrids can save up to \$30,000 per linear mile of track. The ease of geogrid installation not only accelerates construction schedules, it also eliminates the cost of special labor and equipment. With the option to install Tensar TriAx Geogrids in wet conditions, contractors can maximize their productivity in inclement weather.

Since Tensar TriAx Geogrids can be installed directly over existing weak subgrade soils, the costs associated with subgrade excavation, disposal, and replacement or chemical treatment (along with the curing time for chemical treatment) can be eliminated. With shallower excavation, the potential costs associated with the relocation of utilities can often be eliminated as well.

Since track maintenance is a significant and ongoing expense, life cycle cost savings are an additional benefit of using TriAx Geogrids. With the current (and rising) cost of maintenance, railway owners must continuously seek the most cost-effective, immediate and long-term maintenance solutions.

Over the long term, Tensar TriAx Geogrids preserve the integrity of the railway structure by confining the ballast and sub-ballast layers. This typically extends the period between maintenance operations by a factor of three to five times (and the design life of heavy-duty pavements at intermodal facilities by three to six times). Finally, in reducing the deflection of the trackbed during loading, Tensar TriAx Geogrids extend the life of mechanical track components including rails, ties and insulated joints.

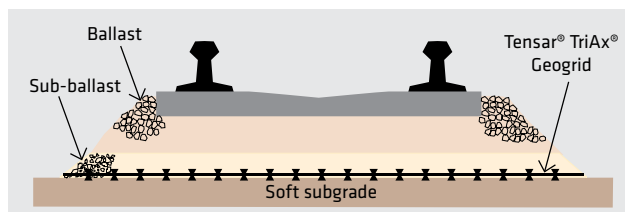


FIGURE 3a: Sub-ballast stabilization provides improved bearing capacity.

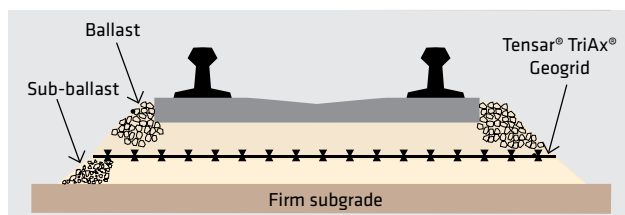


FIGURE 3b: Ballast stabilization leads to increased maintenance intervals.

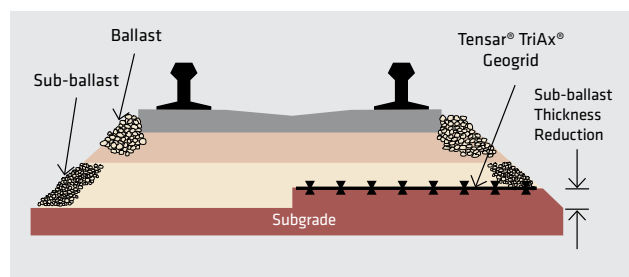


FIGURE 4: Trackbed thickness reduction.



IMAGE A: TriAx TX190L Geogrid was in good condition with no damage observed while continuing to support ballast near the surface.



IMAGE B: TriAx TX190L Geogrid can withstand a typical rail ballast installation procedure while also reducing maintenance intervals.

Research Summary

Tensar and independent authorities have extensively studied the use of TriAx® Geogrid in rail applications. Here are just a few recent field studies that have quantified the benefits of the Spectra® Rail System:

TRANSPORTATION TECHNOLOGY CENTER FIELD STUDY SHOWCASES INCREASED MAINTENANCE INTERVAL – CAPTINA, OHIO

In a recent field study undertaken by Transportation Technology Center, Inc. (TTCI) in conjunction with Norfolk Southern and Tensar, TriAx® TX190L Geogrid was installed on a track with a long history of settlement issues. The trackbed was over 100 years old and was constructed over compacted clay fill so it was necessary to place ballast in this section on a weekly to bi-weekly basis for the last 30 years. Tensar® TriAx® TX190L Geogrid was installed in the ballast and lateral trench drains were excavated at ballast pocket locations to upgrade the site drainage.

After five months of track use, the condition of the TriAx TX190L Geogrid was examined. As shown in the images A and B, the TX190L Geogrid was in good condition with no damage observed while continuing to support the ballast near the surface. The results of the track settlement survey indicated a significant increase in soil modulus and track stability and track maintenance was reduced from a weekly or biweekly to approximately nine month intervals. This research study demonstrates that the stiff TX190L Geogrid can withstand a typical rail ballast installation procedure while also reducing maintenance intervals.

REDUCTION IN TRACK DEFLECTION AND SUBGRADE PRESSURE ON GEOGRID-STABILIZED TRACK – WILSONVILLE, ALABAMA

In order to develop geogrid performance data, research was conducted in 2011 at a new staging track section in Wilsonville, AL. The performance of geogrid-stabilized tracks was evaluated and compared to an unstabilized section. The trial

area was divided into four test sections; two of the sections were stabilized with Tensar® TriAx® Geogrids (TX130s and TX160), one section was stabilized with Tensar BX Type 2 Geogrid, and one section was left unstabilized to serve as a control section. All sections consisted of 8 in. of sub-ballast and 12 in. of new ballast. Vertical track deformation and pressure at the top of the subgrade were monitored over time.

Results indicated that the sections incorporating integrally formed, punched and drawn geogrid experienced continued reduction of stress. The subgrade pressure measurements indicated even better performance for the sections using TriAx Geogrid when compared with the Biaxial® Geogrid section. In addition, the deflection coefficient of variation decreased within the geogrid-stabilized sections over the measured time periods while it increased significantly within the control section not stabilized with geogrid.

FIFTY PERCENT SUB-BALLAST REDUCTION – PIERRE, SOUTH DAKOTA

Due to low bearing capacity subgrades, a six-mile long section of track near Pierre, SD had a long history of excessive settlement issues. As a result, the track was subjected to a permanent 5 mph speed restriction.

In order to address the settlement problems in two different sections, it was first proposed to remove the existing track and unstable subgrade soil and install 12 in. ballast and 12 in. sub-ballast. However, after working with Tensar, design engineers determined that a roadbed stabilized with Tensar® TX160 Geogrid could support rail traffic with the required sub-ballast thickness reduced from 12 in. to 6 in. After the installation, results showed that track settlements were reduced for both sections. Not only did TriAx Geogrid successfully reduce the required sub-ballast thickness, but it also reduced the amount of excavation and the overall construction time.



IMAGE C: To stabilize the sub-ballast under a new rail line, geogrids are simply rolled out directly on top of the prepared subgrade.



IMAGE D: Existing track can be jacked up so that new geogrid and ballast can be added.

Installation

SITE PREPARATION

Tensar® TriAx® Geogrid is quick and easy to install. Smooth, graded surfaces are ideal, but if this is not possible, any protruding objects including tree stumps, branches, boulders, etc. should be removed. Then, any hollows resulting from removal operations should be backfilled. Whenever possible, the subgrade surface should be crowned slightly to promote positive drainage away from the construction area.

GEOGRID PLACEMENT

There are distinct methods for placing geogrids for (1) the construction of new rail lines and (2) the rehabilitation of existing rail lines. To stabilize the sub-ballast under a new rail line, geogrids are simply rolled out directly on top of the prepared subgrade (Image C). A 1 ft to 3 ft (300 to 900 mm) shingle-style overlap, placed in the direction of the fill advancement, is sufficient to ensure stability across the installation. The actual overlap length and any anchoring pattern required are dependent on the subgrade strength (the weaker the subgrade, the greater the overlap).

Multiple approaches may be used to rehabilitate an existing rail line. The installed track and underlying ballast may be completely removed, after which the geogrid is placed in a way similar to new rail construction. Alternatively, the existing

track may be jacked up, and the underlying ballast removed prior to geogrid installation (Image D). The track is then lowered, and a track-mounted ballast machine places and compacts new ballast on top of the geogrid.

Special track-mounted maintenance equipment has also been developed recently for ballasting operations. This ballasting machine lifts and cleans existing ballast as it advances down the track. For projects requiring the stabilization of recycled ballast, the machine can be modified to roll out the geogrid during routine maintenance operations without a significant addition of time.

BALLAST COMPACTION

Compaction of loosely placed ballast is typically completed with a track-mounted tamping machine. To prevent damage to the geogrid, a minimum clearance of 4 in. (100 mm) between the bottom of the compaction tines and the surface of the geogrid is required.



Placing and grading ballast stone on a TriAx Stabilized trackbed

Design Technology

SPECTRARAIL™ SOFTWARE

SpectraRail™ Software provides geotechnical engineers the most powerful tool available for evaluating design options and optimizing railway systems using Tensar® Geogrids.

Developed specifically for Tensar's Spectra® Rail Railway Improvement System, SpectraRail Software enables users to:

- ▶ Evaluate and compare designs for both unstabilized and mechanically stabilized rail roadbeds with comprehensive cost analysis for each alternative
- ▶ Estimate track settlement for a specific level of performance

SpectraRail Software is a comprehensive, systems-based software suite that offers the full benefits of Tensar's knowledge and experience in analyzing both sub-ballast stabilization and ballast optimization applications. These applications incorporate Tensar® TriAx® Geogrids, key components of the Spectra® Rail System (Images E and F). This software is available free of charge following the completion of a free training module delivered by a Tensar specialist. For more information on SpectraRail Software, contact your local Tensar representative by calling **800-TENSAR-1** or email us at techsupport@tensarcorp.com.

DESIGN SUPPORT AND PROJECT ASSISTANCE YOU CAN RELY ON

As the worldwide leader in geogrid technology and design support, Tensar is committed to the success of your rail stabilization project. Our products and technologies are backed by the most thorough quality assurance practices in the industry. We provide comprehensive design and site assistance for every stage of a Spectra Rail System project. For example, we'll provide support to analyze local soil conditions at no charge. This service delivers a more accurate assessment of in-place soil parameters such as stiffness and strength of near-surface soils, leading to a more reliable and economical design.

Given a specific set of soil and proposed loading conditions, a full design section can be developed by Tensar to include a trackbed section in full compliance with AREMA guidelines. Pavement sections for intermodal facilities can also be developed using our state-of-the-art design software. In addition, we can provide case studies, system specifications, technical notes, installation guidelines, preliminary cost estimates as well as additional supporting documentation. Altogether, Tensar's engineers and technical support staff, regional managers and national distribution network strive to keep our systems at the forefront of today's design technology to meet customer needs. Rely on the experience, resources and expertise that have set the industry standard for over three decades. For more information on the Spectra Rail System, call **800-TENSAR-1**, e-mail info@tensarcorp.com or visit www.tensarcorp.com.

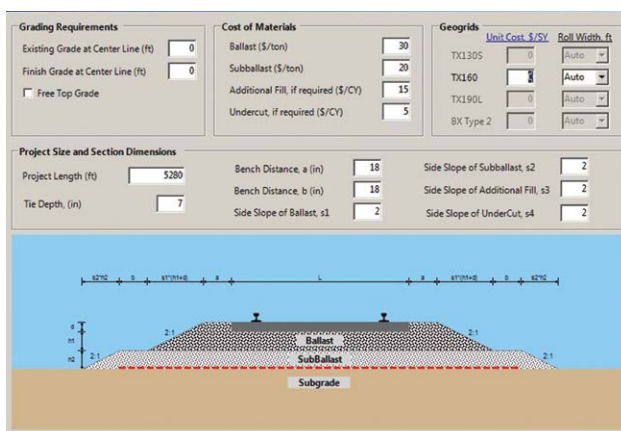


IMAGE E: SpectraRail Software analyzes both sub-ballast stabilization and ballast optimization applications incorporating TriAx Geogrid.

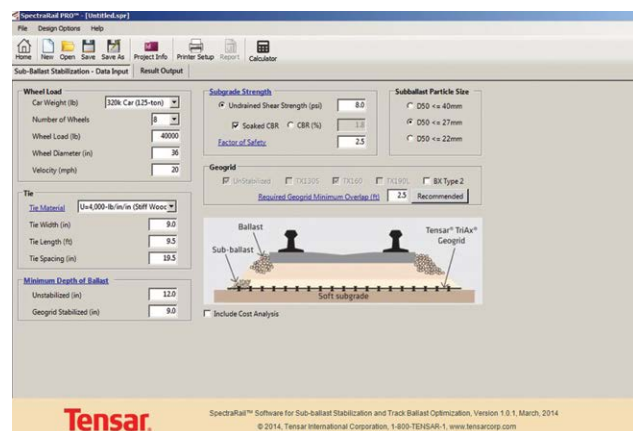


IMAGE F: SpectraRail Software can estimate track settlement for a specific level of performance.

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