Performance verification of a geogrid mechanically stabilised layer

Vérification de la performance d'une couche stabilisée mécaniquement par une géogrille

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ABSTRACT: As part of the study to evaluate performance of a geogrid stabilised unpaved aggregate base overlying relatively weak and non-uniform subgrade soils, a controlled field study was conducted in Weirton, West Virginia, USA. A punched and drawn polypropylene triaxial geogrid was installed at the interface between a soft clayey subgrade and crushed limestone. In-ground pressure cells were used to monitor horizontal stress within the subgrade and base throughout subsequent compaction and traffic loading. The results demonstrated that the lateral stress in the subgrade were approximately ¼ that of the control section and in addition, the geogrid confines unbound aggregate leading to an increased lateral stress and a higher resilient modulus for the stabilised base layer. To verify that these results are applicable to different subgrade and aggregate materials, additional full-scale field tests were conducted in Salt Lake City, Utah, USA. A total of four pressure cells were installed in test section, at spacings of 2.6 and 2.9 metres from the centerline and offset 3 metre parallel to the direction of travel. Pit run material was used as a base layer in this study. Pit run gravel is unprocessed material that contains all sizes of rock. The results show that the horizontal pressures within the subgrade created by both the static and live loading conditions were significantly reduced by using the geogrid whereas a >80% increase in horizontal pressures were measured for the control section after placement of aggregate fill. Post-traffic trenching of the control section found significant mixing of the subgrade materials, whereas very little intermixing of the subgrade materials was reported for the stabilised section. This paper presents the results and analysis from these field studies. The results confirm that the geogrid promotes improved aggregate confinement and interaction, leading to enhanced structural performance of the unpaved aggregate base.

RÉSUMÉ : Dans le cadre d'une étude pour évaluer la performance d'une géogrille pour stabiliser une couche granulaire non revêtue sur des sols de fondation de faible portance et hétérogènes, une étude expérimentale in-situ a été réalisée à Weirton, Virginie-Occidentale, Etats-Unis, Une géogrille triaxiale, fabriquée à partir d'une feuille de polypropylène perforée et étirée a été installée à l'interface entre un sol de fondation argileux mou et une couche de concassé calcaire. Des capteurs de pression ont été installés dans le sol pour mesurer la contrainte horizontale dans le sol de fondation et la couche de gravier pendant le compactage et la circulation. Les résultats ont montré que la raideur latérale dans le sol de fondation était approximativement le quart de celle de la section de contrôle et par ailleurs, la géogrille confinait les agrégats granulaires conduisant à une augmentation de la raideur latérale et de la rigidité de la couche de base stabilisée. Pour vérifier que ces résultats sont applicables à différents types de sols de fondation et à d'autres matériaux granulaires, d'autres essais in-situ à grande échelle ont été réalisés à Salt Lake City, Utah, Etats-Unis. Un total de quatre capteurs de pression ont été installés dans les sections d'essai, espacés de 2,6 et de 2,9 mètres de l'axe et décalés de 3 mètres parallèlement à la direction de déplacement. Un matériau non traité a été utilisé comme couche de base dans cette étude. Les résultats montrent que les pressions horizontales dans le sol de fondation créées par les deux conditions de chargements statique et dynamique ont été significativement réduites par l'utilisation de la géogrille, alors qu'une augmentation de 80% des pressions horizontales a été mesurée pour la section de contrôle après la pose de matériaux d'agrégats, par rapport à la section stabilisée. Cet article présente les résultats et l'analyse de ces études in-situ. Les résultats confirment que la géogrille favorise le confinement et l'interaction des agrégats, conduisant à améliorer la performance structurelle de la couche granulaire non revêtue.

KEYWORDS: Field trafficking performance, Triaxial geogrid, Lateral stress, and Resilient modulus.

1 INTRODUCTION.

In cases where a gravel surfaced road is required over subgrade conditions that are unable to adequately support the traffic loads, geogrids are commonly used to stabilize the aggregate base course and improve pavement performance by decreasing the load distributed to the subgrade. The aggregate that is directly above the geogrid is laterally confined and the result of this enhanced confinement leads to an increase in the resilient modulus of aggregate adjacent to the geogrid. As a result, the stabilised aggregate spreads surface loads over a wider area of subgrade. In general, an equivalent stabilised road section thickness yields an increased allowable traffic load compared to an unstabilised road section.

Geogrids have been used successfully to improve the performance and increase the design life of unpaved roads since the 1970's. Nonwoven geotextiles have been efficient in applications that require the separation of aggregate layers from the underlying subgrade soil.

Throughout the history of geosynthetics, monitored full-scale field studies have been extensively utilized to study the performance of geogrid stabilised sections. Although more sophisticated and precise methods, (i.e., numerical modeling and laboratory test models) can be utilized to study specific variables and/or to optimize a geosynthetic, a basic field study remains as one of the most effective means of providing a definitive proof of performance.

Full scale research has provided guidance, basic criteria and information for the use of geogrids in roadway design (Tingle and Webster 2003). Subgrade bearing capacity factors of the unstabilised and stabilised sections were determined using empirical data from full scale testing performed by the Engineering Research and Development Center (ERDC). The calculated bearing capacity factor of the geogrid stabilised section was more than double that of the unstabilised section.

This paper presents the in-ground stress cell measurements from two full-scale field tests to validate the enhanced confinement effect associated with use of an integrally formed punched and drawn geogrid.

2 FIELD STUDY 1 - WEIRTON, WEST VIRGINIA, USA

2.1 *Research background*

A field study at a site located in Weirton, West Virginiawas developed to evaluate the support conditions of a mechanically stabilised crushed limestone layer on soft clayey subgrade (White et al. 2011). In-ground piezoelectric earth pressure cells (EPC) were used to measure horizontal stress below and above the geogrid location versus the passage of construction and truck traffic over the course of test pad construction and trafficking.

Goals of this field investigation were to:

- Validate fitness for use of geosynthetic products in a challenging subgrade improvement application for construction and trafficking of an unpaved road.
- Verify the enhanced confinement effect associated with the use of geogrid due to geogrid-aggregate interlock.
- Verify the degree of load spreading by recording lateral stresses within the subgrade.

2.2 *Test section construction*

The subgrade soils beneath the test tracks were excavated to a depth of 900mm below the surface. The excavated material was replaced with a uniform lean clay (CL) material. The clay material was placed in the test tracks in uniform 0.35 metre thick loose lifts and mixed thoroughly to a uniform consistency with a roto-tiller. Water was added and several passes of the tiller were used to arrive at a moisture content that produced a subgrade California Bearing Ratio (CBR) of approximately 2 to 3 %.

Geogrids were installed on top of a finished subgrade. Physical properties of geogrid are summarized in Table 1.

Table 1. Summary of geosynthetic treatments.

Type	*Physical Properties*
Polypropylene triangular aperture geogrid	Radial Stiffness = 300 kN/m @0.5% strain

Vertical and horizontal stress measurements were taken in the subgrade and about 150mm above geogrid/base material. Figure 1 illustrates the layout for horizontal and vertical stress cells.

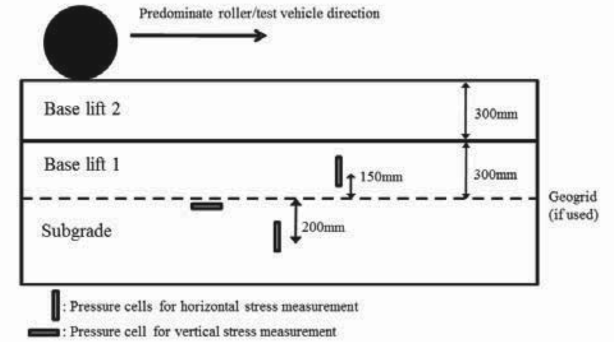

Figure 1. Cross Section of instrumentation installation.

Then, a base course aggregate (Ohio Department of Transportation 304, base course material) was placed in two compacted 300mm lift thicknesses. The crushed limestone was classified as a GP-GM with about 8 percent of fines passing the No. 200 sieve.

Cardboard is used as a temporary liner to contain the silica sand backfill around the EPC (See Figure 2). Use of the sand ensured a uniform stress was applied to the EPC surface.

Figure 2. Placing horizontal earth pressure cell at the bottom of the base layer.

2.3 *Results.*

A Ford L8000 dump truck was used for trafficking of the constructed test sections. The vehicle was loaded to a gross vehicle weight of 18,370 kg.

Figure 3 depicts the readings of dynamic horizontal stresses within the subgrade versus the passage of construction and truck traffic over the course of test pad construction and trafficking. Evident within Figure 3, is the minimal amount of horizontal post traffic stress remaining within the subgrade in comparison to the level found in the control section. The lateral stress below the geogrid is a little over 5 kPa versus 20 kPa for the control test section. This equates to a stress state value that is 25% of the control stress state thus indicating a high level of subgrade protection. This work demonstrated an enhanced fully confined zone above the geogrid resulting in uniform vertical stress across the subgrade resulting in less lateral stress.

Figure 4 depicts the horizontal stress state, post trafficking, exhibited above geogrid. In contrast to the control, the geogrid confines the unbound aggregate leading to an increased lateral stress within the aggregate. The results demonstrate the inclusion of geogrid at the interface of soft subgrade and aggregate layers affects the development of the "locked-in" horizontal stress following loading. A higher horizontal stress within the stabilised aggregate layer gives a direct indication of the lateral restraint mechanism. The result of increased aggregate stresses leads to an increase in the resilient modulus of aggregate adjacent to the geogrid.

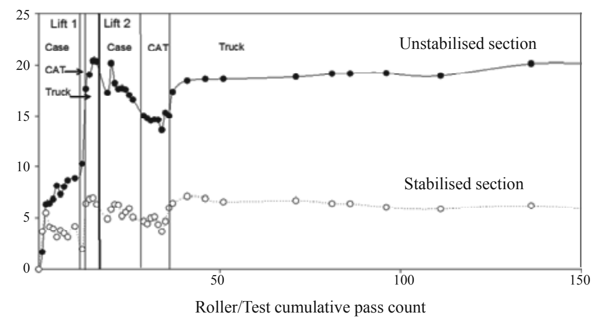

Figure 3. Horizontal stress within the subgrade layer after roller compaction and test vehicle passes (White, et. al., 2011).

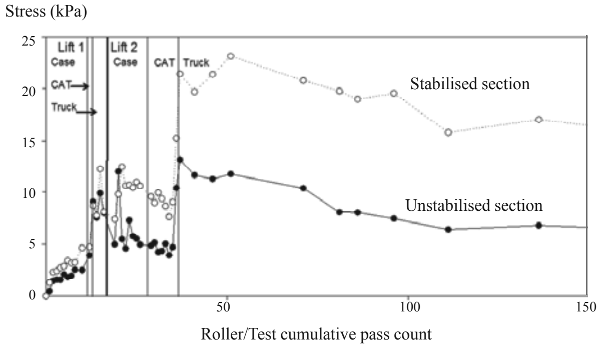

Figure 4. Horizontal stress within the base layer after roller compaction and test vehicle passes (White, et. al., 2011).

Field determination of the relative density values for the second or upper subgrade lift after the completion of 21 truck passes shows 90.2% and 98.5% relative density values were achieved on the control section and stabilised section, respectively. These numbers demonstrated that the aggregate placed over the geogrid can be compacted to a much higher degree than the unstabilised control section.

Lateral stress ratio (K) is calculated as the ratio of total horizontal to total vertical stresses for the subgrade and subbase layers following roller and trafficking passes. Resulting values are presented in Table 2. The calculated K values demonstrate that during trafficking, the K values are about 0.3 to 0.7 for the subgrade and 0.5 to 0.7 for the subbase for all test sections. However, the K values after 75 trafficking passes show buildup of horizontal stresses with relatively high K values in the control section subgrade layer compared to the geogrid stabilised section. The stabilisation ratio provides a clear indication of degree of improvement. For this study the geogrid results in a section that is 8 times better than the control with regard to stress distribution.

Table 2. Performance comparison between test sections.

Section	$K_{subgrade}$	K_{base}	*Stabilisation Ratio*
Control section	3.2	1.2	0.4
Stabilised section	1.0	3.2	3.2

3 FIELD STUDY 2 - SALT LAKE CITY, UTAH, USA

3.1 Research background

A field study at a site located in Salt Lake City, Utah, United Stated of America was conducted to evaluate the effect of a mechanically stabilised platform to bridge over challenging soft subgrade areas. All test sections are backfilled with 150-mm minus pit run (unprocessed) gravel. A total of four sections were constructed and trafficked and two of the sections were stabilised by a layer of integrally formed punched and drawn triangular aperture geogrid placed at the interface between the subgrade and bridging material.

In-ground piezoelectric earth pressure cells (EPC) were used to evaluate the support conditions of the test sections. Measurements of tire ruts were recorded during the survey between passes of the haul truck.

Goals of this field investigation were to:

- Validate ability of a geogrid to reduce lateral pressures within the subgrade under heavy loading conditions and very soft soils.
- Assess the ability of geogrid to stabilize pit run gravel and quantify the benefits for different conditions and loading scenarios.
- Provide surface and subgrade data on heavier loading scenarios.

3.2 Materials.

3.2.1 Subgrade soil and pit-run gravel

Test beds consisted of two materials in this study – low plasticity clay subgrade and pit-run gravel material. A Dynamic Cone Penetrometre (DCP) test was performed in accordance with ASTM D6951-03 using a 4.6-kg single mass hammer. Results were used to determine the strength of subgrade with depth. The near surface California Bearing Ratio (CBR) for the subgrade material varied from about 0.2% to 0.4%.

Aggregate fill material consisted of pit run gravel with a maximum particle size of 150 mm. An enhanced, second generation University of Illinois Aggregate Image Analyzer (UIAIA) was used to determine morphological indices, such as angularity index, AI (Rao et al., 2002) and surface texture index, ST (Rao et al., 2003) of the pit run gravel used in the test. Angularity is critical for aggregate interlock and surface texture has been found to directly influence friction between aggregate particles as well as the strength of the aggregate. The AI and ST indices are determined based on the particle image outlines obtained from each of the top, side and front of coarse particles. Morphological index results of the aggregate samples are presented in Figure 5 and 6.

About 88% of the aggregate samples have angularity index values that are less than 325 and surface texture index values less than 1.375. These values indicate that the pit run gravel used in this study consists of rounded and very smooth surface aggregate particles.

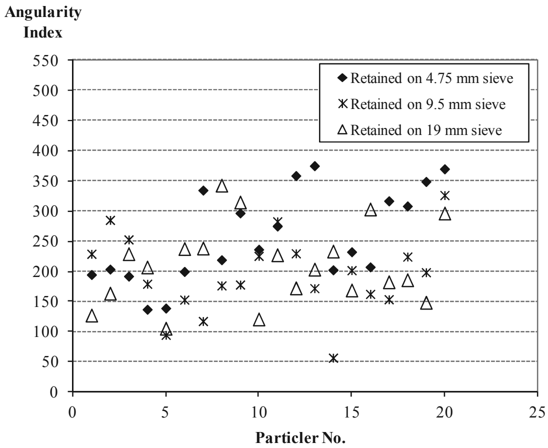

Figure 5. Angularity Indices of the Pit Run Gravel.

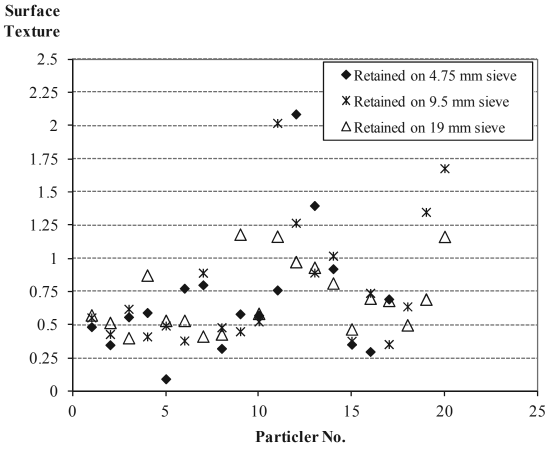

Figure 6. Surface Textures of the Pit Run Gravel.

3.2.2 Geosynthetics

Two geosynthetic materials were used during this investigation. Some physical properties of each geosynthetic material are summarized in Table 3.

A nonwoven geotextile served as a separation layer in conjunction with a triangular aperture geogrid below the aggregate layer. Based on our understanding of the site subgrade soils and overlying pit-run aggregate, a nonwoven geotextile was recommended for use as a separation layer.

Table 3. Summary of geosynthetic treatments.

Type	*Physical Properties*
Polypropylene triangular aperture geogrid	Radial Stiffness = 300 kN/m @0.5% strain
Polypropylene nonwoven geotextile	Weight = 8oz/yd^2

3.3 *Test section construction*

Four test sections were tested during this field study. All test sections consisted of a 300mm thick layer of pit run materials placed over the subgrade. Two sections are stabilised by a layer of geogrid placed at the interface between the subgrade and pit run material. Each test section was approximately 7 metre wide by 10 metres in length. Two EPCs were placed in each test section subgrade to monitor horizontal stress in the subgrade. In general, the approximate angle of distribution of stress within a properly designed geogrid stabilised section is 45 degrees. Therefore, EPCs were placed at 0.9 metre and 1.0 metre from the edge of the wheel path. Pit runmaterial was placed on top of the geogrid by a CAT D8 dozer in a 900mm thick lift. After placement of pit run material, lines were painted on the surface of the road at 0.3 metre intervals from the centerline within the areas over the pressure plates.

3.4 *Results*

Test sections were trafficked by a Volvo A40F articulated truck. The loaded truck produces a ground contact pressure of 176 kPa under each wheel. There was some surface movement of the fill material (due to the smooth rounded aggregate), but no significant deformation of the section was noticed within the wheel path over the course of 50 passes.

The stresses as presented represent the change in ground stresses under the accumulated trafficking passes. As expected, higher stresses are recorded within the control section. Stress measurements in Figure 7 indicate that the stresses of the control section were in the range of 33 to 60 kPa depending upon the distance from wheel path. The stresses of triangular aperture geogrid stabilised section were in the range of 6 to 11 kPa.

The other two sections (control and stabilised) were lightly trafficked. As no significant surface deformation was noticed within 23 passes, sections were then cut down from 900mm in height to 600mm by a CAT 980H loader.

Traffic resumed post-cut. Significant deformation occurred after the first pass across the control section. The trafficking was stopped after 1 additional pass. There was no indication of structural distress in the stabilised section. Stress measurements taken from the first pass are shown in Figure 8. The results indicate that the stresses of the control section were in the range of 48 to 120 kPa, whereas the stresses within the stabilised section were in the range of 8 to 29 kPa.

After the trafficking test was completed, trenches were excavated to observe subgrade conditions. A significant amount of intermixing of the pit run material and subgrade interface occured within the 600mm thick control section. Very little intermixing of the subgrade materials was observed in all other sections including the 600mm thick triangular aperture geogrid stabilised section.

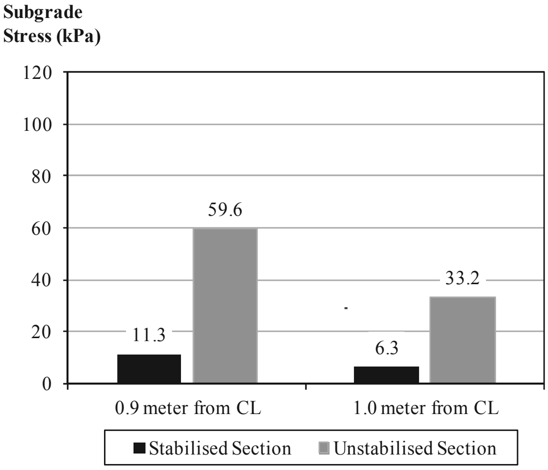

Figure 7. Subgrade pressures of 900mm sections.

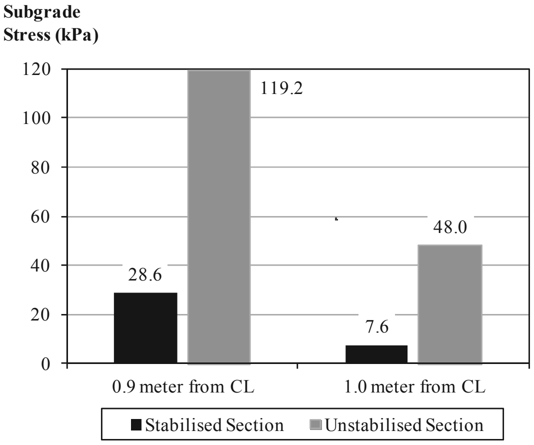

Figure 8. Subgrade pressures of 600mm sections.

4 CONCLUSIONS

The field tests have demonstrated benefits in terms of a dramatic reduction in subgrade stress. Rut depth measurements showed all geogrid stabilised sections performed significantly better than the unstabilised controls. In-ground stress cell measurements showed that higher horizontal stress developed within the stabilised aggregate layer during compaction and this was maintained throughout trafficking. The stabilisation ratio calculated as the ratio of horizontal stresses in the base and subgrade layers provides an indication of field trafficking performance. Results of the second study validate the performance of the triangular aperture geogrid examined in two full scale trafficking studies.

5 REFERENCES

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