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A full-scale field approach for evaluating the geogrid reinforcement effectiveness in flexible pavement

Une approche de terrain à grande échelle pour évaluer l'efficacité du renforcement des géogrilles dans les chaussées souples

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ABSTRACT: An Automated Plate Load Test (APLT) device was used to conduct tests on pavement sections on the South Riverfront Drive project in Mankato, MN, USA. In situ testing included cyclic APLTs performed on the compacted aggregate base layer to determine composite, base layer, and subgrade layer resilient modulus (M_r) values. Tests were conducted at eight test points, with one test location in each of the eight sections. The eight test configurations were constructed by varying geogrid types (i.e., light-duty biaxial, heavy-duty biaxial, light-duty triaxial, and heavy-duty triaxial geogrids), geogrid locations in the base course (i.e., at the interface between aggregate base course and subgrade or within the aggregate base course), and base aggregate thicknesses. Testing results included resilient modulus, deflection, and permanent deformation of the pavement foundation for evaluating geogrids' structural benefits. The results show that geosynthetic reinforcement can generally decrease permanent surface deformation and increase the base resilient modulus of pavement sections. High duty triaxial geogrid at the base/subgrade layers' interface position represents the best performance of geogrid reinforcement, among other sections with the base thickness of 254 mm and triaxial geogrids overall represent better performance than biaxial geogrids.

RÉSUMÉ : Un test automatisé de charge de plaque (APLT) effectué sur des sections de test sur le projet South Riverfront Drive dans la ville de Mankato, MN. Les tests in situ comprenaient des APLT cycliques sur la couche de base d'agrégat compacté pour déterminer les valeurs du module résilient (Mr) de la couche de base et de la couche de fondation. Des tests ont été menés à huit points de test, avec un emplacement de test dans chacune des huit sections. Les huit configurations de test construites par différents types de géogrilles (c.-à-d. Géogrilles biaxiales légères, biaxiales lourdes, triaxiales légères et triaxiales lourdes), emplacements des géogrilles dans la couche de base (c.-à-d. À l'interface entre la base des agrégats couche de fond et de fondation ou dans la couche de base des agrégats) et les épaisseurs des agrégats de base. Les résultats des tests comprenaient le module de résilience, la déformation et la déformation permanente de la fondation de la chaussée pour évaluer les avantages structurels des géogrilles. De plus, les résultats montrent que le renforcement géosynthétique pourrait réduire la déformation permanente de la surface et augmenter le module élastique de base des sections de chaussée de plus de 15 et 20%, respectivement. Une série de facteurs d'équivalence granulaire (G.E.) développés par cette étude peuvent être utilisés par les ingénieurs concepteurs et les applications industrielles pour incorporer des géosynthétiques dans leurs conceptions de chaussées.

KEYWORDS: Granular Equivalent factor, Geosynthetic reinforcement, Full-scale field test, Flexible Pavement

1 INTRODUCTION.

Pavement layers are designed to support loads generated by vehicle traffic and safely distribute the loads to the underlying base layers and subgrade soil. There are three layers in the conventional flexible pavement: asphalt layer, aggregate base course layer, and underlying subgrade layer. Surface rutting is one of the common types of pavement distresses, which happens when the wet and weak subgrade soil underneath the pavement cannot provide sufficient strength to support the loads. How to build the pavement over wet and weak soil has always been a challenge for pavement designers. One typical method in some US states is to create a stiffer platform by improving the subgrade material's strength by using cement or lime to stabilize the subgrade materials' upper zone based on the subgrade soil type. Geosynthetics are another popular solution that is environmental-friendly and economical when reinforcing and stabilizing pavement systems over the weak and wet soil layer. High strength woven geotextiles and geogrids provide reinforcement effects for base aggregates and stabilization benefits for subgrade materials due to their reinforcement mechanism including lateral confinement, increasing bearing capacity, tension membrane, and separation (Zornberg 2017).

Early application of geosynthetics in the construction of roadways started in the 1970s. Since then, many investigations have been performed and assessed the benefits of geosynthetic reinforcement (e.g. (Al-Qadi et al. 1994, Perkins & Cuelho 1999, Berg et al. 2000, Satvati et al. 2020)). Mainly two types of geosynthetic products applied in the experimental investigations in the literature: geotextiles and geogrids. The results of the investigations indicate that geosynthetic reinforcement is a useful product to extend the service life of the pavement (Al-Qadi et al. 1994, Perkins 2002). Further, geosynthetics can also reduce the thickness of the base course layer, reduce the development of the rutting, and provide the possibility for pavement construction above soft subgrades (Cancelli & Montanneli 1996, Perkins 2002). These benefits of geosynthetic reinforcement in the pavement are afforded by lateral restraint, separation, and tensioned membrane effect of geosynthetics. Due to load spreading over a broader area on top of the subgrade in geosynthetic reinforced sections, vertical stresses transferred through the geosynthetic reinforced base onto subgrade are lower than the unreinforced sections. High strength woven geotextiles and geogrids can also decrease subgrade stress by absorbing shear stresses (Zornberg 2017).

The geogrid reinforced flexible pavement performance can be affected by many factors, including geogrid stiffness, geogrid aperture and rib sizes, and the geogrid location/depth, hot mix asphalt thicknesses, base aggregate quality, stiffness thicknesses, and subgrade stiffness. Geogrids are used to improve the performance of the flexible aggregate base layer or the railroad ballast layer by enhancing the unbound aggregates. Many investigations have been conducted by researchers using both experimental and numerical approaches for assessing the geogrid reinforcement benefits of pavement sections. (e.g. Zornberg & Gupta 2010, Alimohammadi et al. 2020). The test results indicate that geogrids effectively improve the stiffness and stability of the reinforced structures of the pavement and reduce the accumulated permanent deformation. These results suggest that geogrids reinforcement's effectiveness is more notable in pavements built over soft subgrade soil. The optimal geogrid layer location has been investigated in many studies and recommended by some researchers to be put within the upper one-third of the base layer; however, for a thinner aggregate layer, the reinforcement is recommended to be located at the interface of the aggregate and subgrade layer. It was also proposed that double geogrid reinforcement layers led to better improvement regardless of the geogrid type. With similar tensile moduli, triaxial geogrid provides better improvement compared to the biaxial geogrid (Zornberg 2017).

A full-scale experimental test plan was developed in this research using the APLT system to evaluate geogrids' reinforcement effects on pavements' structural performance. A total of eight test configurations were constructed by varying geogrid types, geogrid locations in the base course, base aggregate thicknesses, and the effects of these variables were studied on the resilient modulus, deflection, and permanent deformation results of the pavement foundation. The test configurations, the test procedure, and the results are discussed in the following sections.

2 TEST SECTIONS, PROJECT LOCATION, AND TEST SECTION ARRANGEMENTS IN THE FIELD

Automated Plate Load Tests (APLTs) were conducted on test sections on the South Riverfront Drive project in Mankato, MN. In situ testing included cyclic APLTs on the compacted aggregate base layer to determine composite, base and subgrade layer resilient modulus (M_r) values. Dynamic Cone Penetrometer (DCP) tests were performed to assess penetration resistance and to develop a California Bearing Ratio (CBR) profile at each test location. Tests were conducted at one test location in each eight test sections.

Figure 1 show the test cross-section details and the field test sections studied using the APLT system. A total of ten test sections were performed to evaluate unreinforced and reinforced base course behavior using different types of geogrids at different locations: Control section 1, Section 1, Section 2, Section 4, Section 5, Section 7, Control section 2, Section 12, Control section 3, and Section 15. No geogrids were installed in the control sections listed above. Biaxial geogrid was used in Section 1, Section 2, and Section 5. Triaxial geogrid was used in Section 4, Section 7, Section 12, and Section 15. For Section 1, Section 2, Section 4, and Section 12, the geogrid products were placed at the interface of the aggregate base course and the subgrade layer. For Section 5 and Section 7, the geogrid was located in the middle of the base course layer. Both light-duty and heavy-duty geogrid products were used in the test sections. The details for the test sections are represented in Figure 1. The main parameters studied are geogrid type (biaxial and triaxial), geogrid stiffness ("light" duty and "heavy" duty), geogrid location/depth, and aggregate base thickness. Figure 2 shows the project location in Mankato in the state of Minnesota. The light and heavy-duty biaxial equivalent modulus properties of the geogrids used in this study are 426 and 928 Mpa and for triaxial geogrid properties are 1085 and 1260 Mpa respectively.

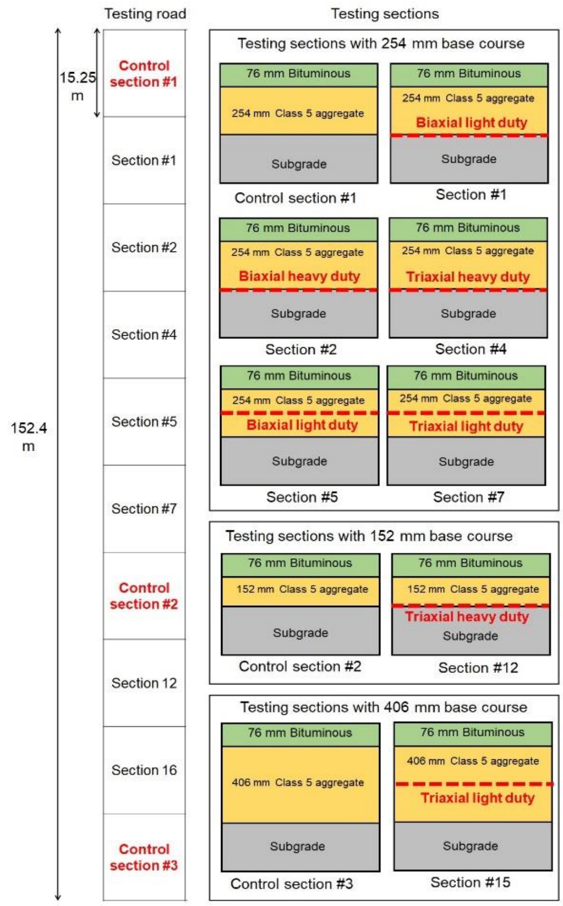

Figure 1. Field test sections

Figure 2. Project location in Mankato city in the state of Minnesota, USA

3 AUTOMATED PLATE LOAD TESTING SYSTEM

The APLT is a system developed by Ingios Geotechnics Inc. to perform fully automated cyclic and static plate load tests, according to ASTM, AASHTO, and European test standards. Plate load testing has been extensively applied in geotechnical engineering to test foundations and assess in-situ pavement foundation support conditions. Modulus of subgrade reaction (k-value) is used in rigid pavement design in the US, evaluated using a 762 mm diameter plate subjected to static load steps. In comparison, strain modulus (E_v) with one or two quasi-static load cycles using a 300 mm plate is used in Europe. Static plate load testing has traditionally been considered time-consuming, difficult, and often too expensive as a routine measurement. The APLT system was designed to provide safe, rapid, state-of-the-art testing of in-situ pavement foundations to overcome previous limitations (Ingios Geotechnics Inc. 2020). In the new AASHTOWare Pavement Design (MEPDG 2004), resilient modulus (M_r) values are used in both flexible and rigid pavement design. The APLT system is developed to evaluate the confining-stress-dependent resilient modulus input values using the universal model. Resilient modulus has only been obtainable from laboratory triaxial tests (AASHTO T 307) or using empirical correlations until now. The advantages of the APLT system is the capability to apply a conditioning stage (i.e., 100+cycles) before testing design values, using confinement control to test on the foundation layer directly (simulating a triaxial laboratory test), plus measuring both the peak, recoverable, and permanent deflections compared to the falling weight deflectometer (FWD) testing. It is well established in the literature that the application of conditioning load cycles and the use of stress control are critical to predicting in-service design values. The APLT accomplishes both of these using an advanced electronic-hydraulic control system (Ingios Geotechnics Inc. 2020).

The APLT system was developed for rapid stationing and testing of pavement foundations, embankments, compacted fill, and stabilized materials. The APLT system can evaluate k-values and E_v-values by rapid static testing, and measure in-situ M_r by cyclic testing considering the influence of the number of cycles, confining pressure, and stress level. The in-situ composite Mr values are presented, adapting the Boussinesq's half-space equation and resilient or elastic deformations assessed from the tests. Using Odemark's equivalent thickness method, the layered moduli information can be extracted from the composite values and verified using independent field measurements (Ingios Geotechnics Inc. 2020).

The APLT system is equipped with an electronic-hydraulic control system which uses the system and decreases operator errors during testing. The APLT system's self-weight can support a reaction force of 7-tons that can be raised to 15-tons to conduct tests using larger plate sizes. The APLT system is facilitated with a remote-controlled scraper blade and uses an auto-level guidance system to smooth uneven surfaces before testing. The Automated Plate Load Testing (APLT) equipment is displayed in Figure 3.

Figure 3. The Automated Plate Load Testing (APLT) system

4 APLT LOADING PATTERN, MATERIAL PROPERTIES, AND SITE CONDITIONS

The APLT loading pattern, geogrid properties, base and subgrade properties, and site conditions are explained in this section.

4.1 *Loading pattern*

In each test section, one thousand four hundred cycles (1400) were conducted except control section 3 and section 15, which were not tested in this study. Deflection basin measurements were obtained at three positions extending away from the plate (2r, 3r, and 4r). Results from cyclic APLTs conducted at six different stress levels were used to determine the in situ "universal" model (AASHTO 2015) (White et al. 2019). The k_{1*}, k_{2*}, and k_{3*} model parameters for the composite ($M_{r\text{-Comp}}$) and stabilized aggregate base ($M_{r\text{-Base}}$) and subgrade layers ($M_{r\text{-Subgrade}}$) were determined for each test point.

4.2 *Geogrid properties, base and subgrade properties*

Four types of geogrids were used in this research including biaxial and triaxial with both light- and heavy-duty strengths. The aggregate base material, which is typically used in Minnesota for the base course of construction projects, used in this research consisted of recycled asphalt pavement (RAP) material classified as the MnDOT "Class 5" aggregate base which is a specialized base aggregate in MnDOT. This aggregates can be classified between a range of A-1 and A-2 according to AASHTO soil classification. Based on field observations during construction, the subgrade near the surface also consisted of RAP material. The test sections' elevation profile was constructed by first cutting the subgrade level and then backfilling with several inches of RAP and recompacting. A series of index properties tests and proctor tests performed on the base aggregate materials in the geotechnical laboratory at Iowa State University.

4.3 *Site conditions*

Figure 4 illustrates the condition of sites and procedure of construction of base and subgrade and setting the geogrids in the construction process. After compacting and stabilizing the subgrade materials with aggregates, the geogrids were installed according to the arrangements illustrated in Figure 1, the base materials were placed and compacted, and then the APLT tests were performed on top of the compacted aggregate.

a) Laying out geogrid b) Placing base course materials

Figure 4. Installation of Geogrids on compacted subgrade

5 PERFORMED QA/QC TESTS IN THE FIELD

In order to measure site variability, a series of tests were conducted using different field devices. These quality control and quality assurance geotechnical tests were performed during the road sections' construction, illustrated in figure 5. These tests were included Light Falling Weight Deflectometer (LFWD) tests on top of the subgrade layer, Dynamic Cone Penetration (DCP) tests on top of the base layer, and sand cone test on top of the base layer. The HUMBOLDT LFWD (HUMBOLDT 2020) is a portable device that measures deflection using falling weight, the degree of compaction, and the soil's dynamic modulus. The LFWD weighs 26 kg and has a 10 kg falling height, which impacts a spring to create 18 milliseconds pulses, and a guide rod (720 mm drop height) supported with a lock pin and loading plate (100 mm, 200 mm, and 300 mm). The DCP consists of 8 kg weights, which fall freely from an upper shaft at a distance of 22.6 inches. It exerts dynamic energy of about 78.5 N.

Figure 5. Light Falling Weight Deflectometer (LFWD) on top of subgrade layer, and Dynamic Cone Penetration (DCP) tests on top of the base layer

6 RESULTS AND ANALYSIS

In this section, the performed APLT test results, QA/QC tests, plus developing Granular Equivalent (G.E.) factor for geogrid reinforced flexible pavement are explained.

6.1. Results of performed tests

Figures 6 through 11 show a summary of performed test results for all test sections in the field locations. From the results, it can be seen that the control section 1 and 2 have higher subgrade resilient modulus than reinforced sections. This causes difficulty in comparing the evaluation of performance of unreinforced with reinforced sections. Figures 6, 7, and 8 show that although the resilient modulus of the base aggregates of reinforced sections are slightly more than unreinforced sections, the combo resilient modulus of the reinforced sections is almost equal or slightly less than reinforced sections. However, figure 9 shows that permanent deformation of all reinforced sections are less then unreinforced sections. This is likely due the increase in resilient modulus of the base aggregate layer by the geogrid reinforcement.

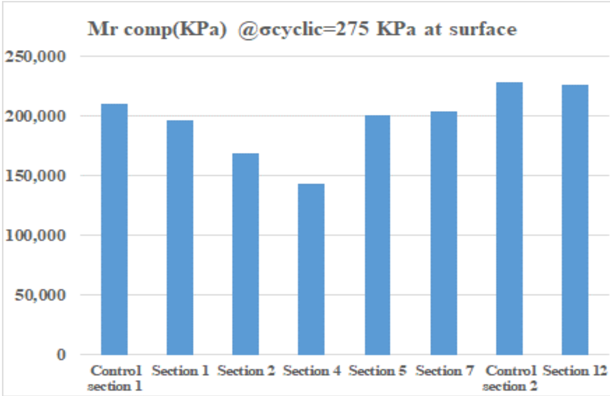

Figure 6. Resilient modulus of all test sections in the field locations

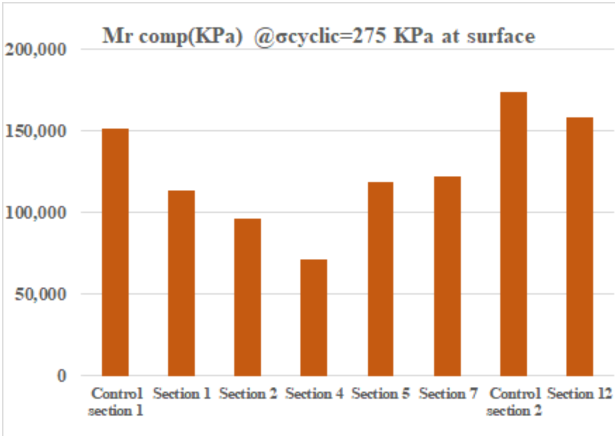

Figure 7. Subgrade resilient modulus of all test sections in the field locations

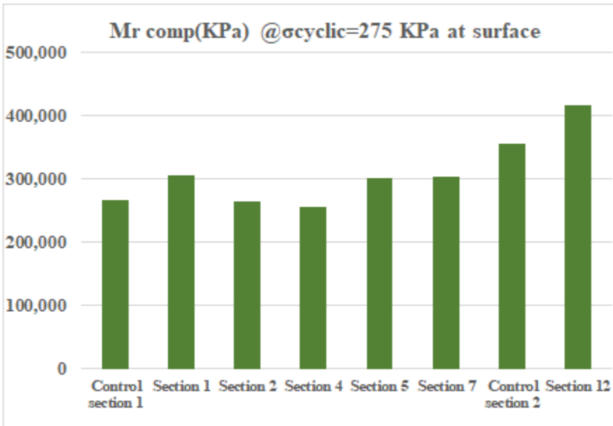

Figure 8. Base aggregate resilient modulus of all test sections in the field locations

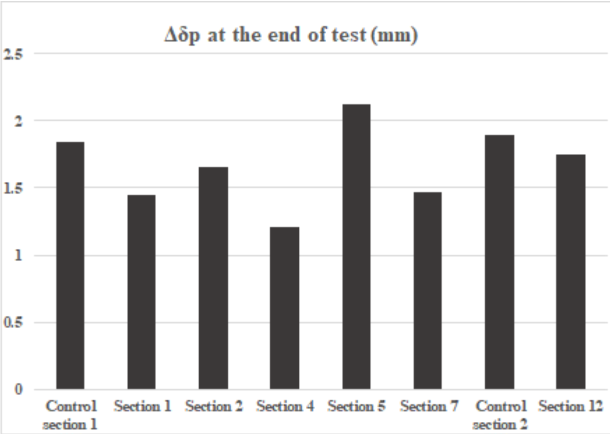

Figure 9. Permanent deformation of all test sections in the field locations

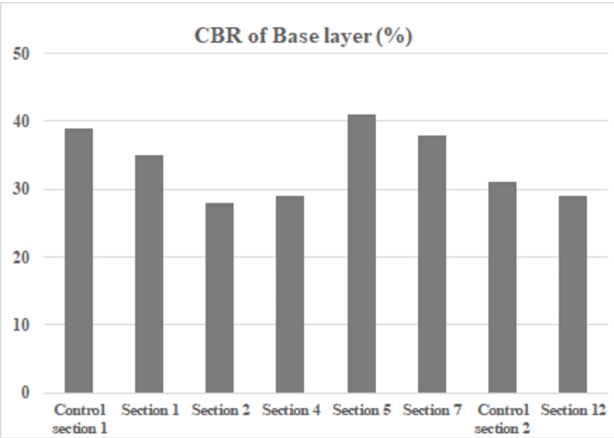

Figure 10. CBR results of the base layer of all test sections performed in the field

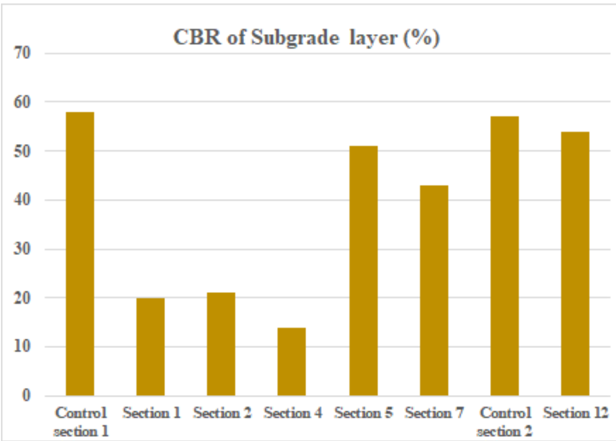

Figure 11. CBR results of subgrade layer of all test sections performed in the field

The results in Figure 9 show that the triaxial heavy duty grid sections have the best performance to reduce the permanent deformation of the pavement surface than the other geogrids. Although literature proves that geogrids with higher stiffness are more effective to reduce permanent deformation of the pavements; it is observed from the figure 9 that the surface permanent deformation of section with biaxial heavy-duty geogrid is slightly more than biaxial light duty stiffness (by comparing the results of sections 1 and 2). It is again probably due to the variables in the strengths of the materials in the site and by comparing the resilient modulus of these two sections it can be seen that the base and subgrade resilient modulus of section 1 is more than section 2. A manhole was located in section 5 which may be the reason why this section shows the most surface deflection among the other sections (despite that the resilient modulus of this section is almost equal to the unreinforced control section 1). In this study Figure 9 shows that locating the geogrid at the base and subgrade position has better performance than the middle of the base position and triaxial geogrids generally represent better performance than biaxial geogrids as well.

The results of LFWD tests above the subgrade layer illustrated in Figure 12 shows the average results of CBR for base and subgrade materials for each test section in the field. Due to the dimensional variability of natural soil deposits, uncertainty in evaluating soil properties for a site is inevitable. As it is obvious from the results, section 5 had the weakest strength of subgrade in the road, and the relevant resilient modulus and deflections are less among other sections. Comparing the results of Figure 12 and Figure 11, it is obvious that results of control section 1 and 2, section 7, section 12 and beginning of the section 5 have consistence results with each other; however, sections 1, 2, 4, and middle and end of section 5 show different trends in Figure 12 compared to Figure 11. It should be mentioned here that Figure 12 represent the results of strength of the subgrade layer before putting and compaction of the base layer and the results of Figure 11 are from converted results from resilient modulus to CBR values from performed tests by APLT system on top of base layer. Table 1 shows the average CBR calculated from performed DCP tests for all sections. Results of Table 1 have consistent results compared to calculated resilient modulus of subgrade from Figure 11; however, the results of DCP tests show higher CBR values for reinforced sections 1, 2, 4, and 7 compared to calculated base course CBR valvules from Figure 10.

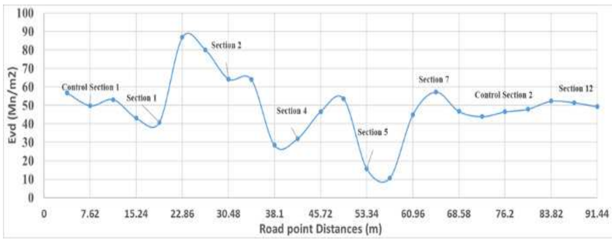

Figure 12. Subgrade Light Falling Weight Deflectometer test results, South Front river Dr., Mankato, MN

Table 1. Average CBR calculated from the performed DCP tests for all sections

Section	C1	1	2	4	5	7	C2	12
Base	37	39	37	39	41	42	36	32
Subgrade	65	24	21	20	50	45	60	59

Sand Cone compaction test results showed the 95 percent compaction degree for the base aggregates section in the field. Figure 13 illustrates the permanent deformation results of triaxial and biaxial geogrids. Figure 13 shows the results of permanent deformation for biaxial geogrids and triaxial geogrids for all performed sections in the field by APLT system. The results from this figure have consistency with the results presented in Figure

9 and the same interpretations and conclusions apply to this figure as well.

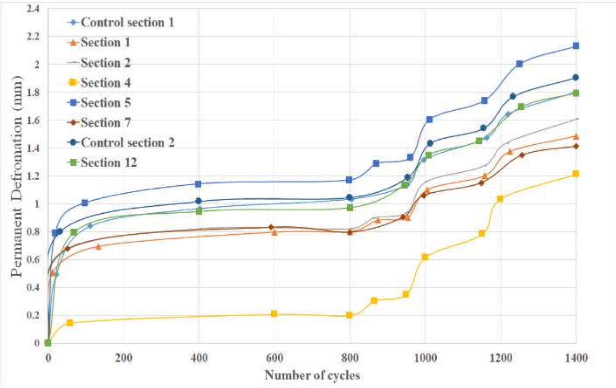

Figure 13. Permanent deformation for Biaxial geogrids and Triaxial geogrids

7 CONCLUSIONS

In this study, a series of full-scale field tests were conducted to determine geogrids' effectiveness under various parameters. These parameters include the geogrid types, the geogrid's aperture, the geogrid's stiffness, the location where to install the geogrid, and the thickness of the base course layer. In this research, a full-scale experimental test plan was developed by using Automated Plate Load Tests (APLTs) to evaluate the reinforcement effects of geogrids on the structural benefits of pavements. A total of eight configurations were constructed with varying geogrid types, geogrid locations in the base course, and base aggregate thicknesses. The effects of these variables on the resilient modulus, deflection, and permanent deformation results of the pavement foundation were studied. After plotting and comparing these results, the following preliminary observations can be made:

- Placing the geogrid layer at the base and subgrade interface layer can significantly reduce permanent deformation (or rutting) and improve the subgrade and the base layers stiffnesses, reduce the permanent surface deformation, and extend the service life of pavement sections.
- M_r-Comp test results indicated that the composite foundation (with base and subgrade are shown in figure 6 through 8) layer has low sensitivity to applied cyclic stress up to 276 KPa. in general, this behavior has been observed in the past testing on recycled asphalt pavement materials.
- Layered analysis results indicate that the Mr-Subgrade generally decreased with increasing applied stress.
- Mr-Comp values in the test sections varied between 143,411 and 228,216 KPa. The lowest Mr-Comp value was in Section 4, and the highest Mr-Comp value was in Control Section 2.
- High duty triaxial geogrid at the base/subgrade layers' interface position represents the best performance of geogrid reinforcement, among other sections with the base thickness of 254 mm.
- Triaxial geogrids generally represent better performance than biaxial geogrids in this study.

8 ACKNOWLEDGEMENTS

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