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Radial stresses and resilient deformations of geogrid-stabilized unpaved roads under cyclic plate loading tests

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ABSTRACT

The performance of geogrid-stabilized unbound aggregate courses over weak subgrade has been studied over the years by many researchers. Previous studies reported that the inclusion of geogrid reduced the permanent deformation on the surface and the vertical stress on the subgrade. This study evaluated the influence of the geogrid on the resilient deformations and radial stresses of the aggregate bases and subgrade. A cyclic plate load was applied through a 0.3-m diameter plate on Kansas type aggregate bases with thicknesses of 0.15, 0.23, and 0.30 m. To investigate the effect of the load intensity on pavement response, the plate load magnitude was increased from 5 to 50 kN with an increment of 5 kN. Displacement transducers were installed at different distances to monitor the permanent and resilient deformations on the surface and subgrade. Horizontally and vertically placed pressure cells monitored vertical and radial stresses within the base and subgrade layers. Test results indicate that the inclusion of a geogrid reduced both the base course and subgrade permanent deformations and changed the radial stress distributions within the base course and subgrade. The geogrid stabilized sections showed greater resilience than the unstabilized sections. The geogrid restrained and recovered the lateral deformation of the aggregate while the unstabilized sections failed due to the progressive lateral displacement.

1. Introduction

Geogrid has been widely used in soil stabilization for many years and has been playing an important role in solving geotechnical problems (Webster, 1993; Giroud and Han, 2004a). Geogrid can be uniaxial, biaxial, or multi-axial with a regular network of integrally connected tensile elements. Uniaxial geogrid carries high tensile loads applied in one direction and is mainly used for retaining walls, slopes, and embankments. Both biaxial and multi-axial geogrids are appropriate for construction platforms, waste containment capping, paved and unpaved roadways and railways.

(Perkins and Ismeik 1997) summarized three potential reinforcement functions involving geosynthetic reinforcement of roadways as: the lateral restraint, the increased bearing capacity, and the tensioned membrane effect. The geogrid confined aggregate results in a stiffer base course and a lower dynamic deflection of the pavement/roadbed structure during traffic loading (Giroud and Han, 2004a,b). Geogrid changes the interface condition between the weak subgrade and the aggregate base. This phenomenon results in and enhances the bearing capacity of the subgrade (Giroud and Noiray, 1981; Giroud and Han, 2004a). When an excessive amount of deformation is accumulated under the applied traffic load, the curved and tensioned reinforcement can develop an upward force to support the load (Giroud and Noiray, 1981; Sharma et al., 2009). In addition to the above mechanisms, the geogrid at the interface between the aggregate base and the weak subgrade prevents the base aggregate from punching into the subgrade and the fines in the subgrade from migrating into the base course (Tingle and Jersey, 2005).

Load distribution within a pavement section acts radially at all levels. For geosynthetic stabilized roadways, traffic load creates a spreading motion of the aggregate, which causes tension in all directions in geosynthetics by the shear interaction between the aggregate and geosynthetics (Perkins et al., 2011; Wang et al., 2014; Bhandari et al., 2015). When subjected to tension in all directions, multi-axial geogrids exhibit more uniform stresses and strain distributions over traditional biaxial geogrids because biaxial geogrids have the tensile stiffness predominantly in two directions whereas multi-axial geogrids have a better ability to distribute the load through 360° with an additional principal direction of stiffness

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(Dong et al., 2011). Therefore, multi-axial geogrid is more effective and efficient in its ability to distribute tension and interact with the granular material under traffic loading.

Many researchers evaluated the performance of the mechanically stabilized base courses using cyclic plate load tests. In these studies, permanent deformations and vertical stresses were the major performance investigated. Tingle and Jersey (2005, 2009) evaluated the performance of the geogrid-stabilized aggregate roads in a full scale model study in terms of the surface deflection, the subgrade deflection, and the vertical stress on the top of subgrade and found that geosynthetics reduced both the vertical deflection and vertical stress. Chen et al. (2009) also studied the influence of the geogrid-stabilized pavements on the subgrade deformation. The tests were conducted inside a test box with dimensions of 2.0 × 2.0 × 1.7 m^3 and a 40 kN cyclic load at a frequency of 0.77 Hz was applied on the test sections through a 305-mm diameter steel plate. The test results showed that the mechanically stabilized base course distributed the applied load to a wider area than the unstabilized section and reduced the permanent deformation of the subgrade. Qian et al. (2011) investigated the unstabilized and multi-axial geogrid-stabilized base courses over weak subgrade constructed in a 2.0 × 2.2 × 2 m^3 box under a 40 kN cyclic load. The test results showed that multi-axial geogrids reduced the surface permanent deformations and vertical stresses at the interface of the base course and subgrade. In addition, the vertical stresses at the interface between the base course and the subgrade increased with the increase of the number of load cycles due to the deterioration of the base course and the inclusion of the geogrids reduced the rate of the deterioration.

The lateral displacement of the geogrid-reinforced granular material was investigated as well. Indraratna et al. (2013) studied the lateral displacement response of the geogrid-reinforced ballast under cyclic loading in a 0.8 × 0.6 × 0.65 m^3 box. In this study, one side-wall of the box was replaced by a setup of five independent movable plates along the depth to measure the lateral deformation. The test results revealed that both the vertical and lateral deformations were influenced by the geogrid type and its placement location. The test results also demonstrated the ability of geogrid in arresting the lateral displacement of the ballast and reducing the vertical settlement.

In pavement design, resilient modulus is an important design parameter. However, the resilient behavior of the geogrid stabilized granular materials has not been well investigated. The existing research results show inconsistencies regarding the resilient behavior of the geogrid stabilized granular materials. Rahman et al. (2013) investigated the resilient moduli and permanent deformation characteristics of the construction and demolition (C&D) materials stabilized with biaxial and multi-axial geogrids. Repeated load triaxial (RLT) equipment was used to determine the resilient moduli of the mechanically stabilized C&D specimens. The resilient modulus values of the mechanically stabilized C&D materials were found to be higher than those of the respective unreinforced material. The permanent deformations of the mechanically stabilized C&D materials were smaller than those of the respective unstabilized material. Yang and Han (2012) proposed an analytical model to predict the resilient modulus and the permanent deformation of the geosynthetic stabilized unbound granular materials under an repeated load triaxial test. Both the test and the analytical results showed that the permanent strains of the geosynthetic stabilized samples were reduced significantly even though the resilient moduli of the samples were not increased obviously. Abu-Farsakh et al. (2007) performed a series of laboratory triaxial tests and evaluated the effects of the geogrid properties, the locations, and the number of layers on the resilient and permanent deformations of the samples under cyclic loading. The test results demonstrated that neither the geogrid type nor the geogrid arrangement had a significant effect on the resilient strain values. Sun et al. (2014a) found that the geogrid stabilized base courses over weak subgrade had higher resilient deformations as compared with the unstabilized test section under the cyclic plate load test. In summary, the resilient behavior of the geogrid stabilized base courses over subgrade has not been fully understood.

As shown in the above studies, the performance of geogrid-stabilized sections has been mainly evaluated in terms of an improved stress distribution and a corresponding reduction in the deformation on the top of the subgrade. In most studies, a 40 kN cyclic load was applied through a 300-mm diameter plate to simulate half of an equivalent single axle load (i.e. a single wheel load). However, there is a need to evaluate the benefits of the geogrid under different load intensities. In addition, radial stresses in base courses and subgrade need to be investigated because the radial stress is directly related to the lateral confinement effect of the geogrid. There is also a need to evaluate the resilient behavior of the geogrid stabilized roadways to understand the influence of the geogrid in roadway performance. Therefore, in addition to the vertical permanent deformation and the vertical stress distribution, the radial stresses and the resilient deformations of the geogrid stabilized road sections under varying loading intensities are necessary to be evaluated.

In this study, large scale cyclic plate load tests were carried out at the University of Kansas. A total of nine sections were tested. The vertical/radial stress distributions and the permanent/resilient deformations of the test sections under varying load intensities were monitored to investigate the effect of the multi-axial geogrid.

2. Materials and test setup

2.1. Base course

In this study, the Kansas Type AB aggregate (also referred to as the AB3 aggregate) was chosen as the base course material. The AB3 aggregate is commonly used for low-volume roads in Kansas. Its physical properties are as follows: specific gravity (G_s) = 2.69, mean particle size (d_{50}) = 4.0 mm, coefficient of curvature (C_c) = 0.83, and coefficient of uniformity (C_u) = 13.3 (Sun et al., 2014a,b). The soil particles passing the No. 40 sieve was tested for the Atterberg limits: liquid limit (LL) = 20 and plastic limit (PL) = 13. Fig. 1 shows the grain size distribution of the AB3. Five modified Proctor compaction tests were performed on the AB aggregate samples at varying moisture contents following ASTM D1557. In addition, the California Bearing Ratio (CBR) tests were performed on samples

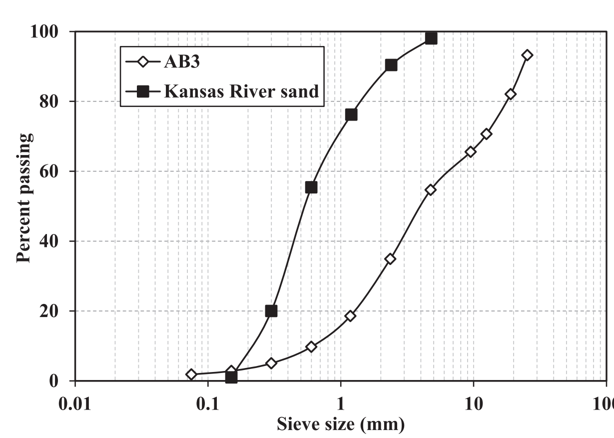

Fig. 1. Grain size distributions of the AB3 and Kansas River sand.