Behavior of triangular aperture geogrid-reinforced bases under static loading

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ABSTRACT: Biaxial geogrids have been successfully used to improve soft subgrade and reinforce base courses by providing lateral confinement. They are relatively strong in the machine and cross-machine directions; however, they are relatively weaker in other directions (for example, 45^o to the machine direction). The new triangular aperture geogrid products just introduced into the market are expected to have a more stable grid structure, which can provide more uniform resistance in all directions. Experiential tests were performed in this study to evaluate the triangular aperture geogrid-reinforced bases under static loading. Unreinforced bases were also tested for the comparison purposes. In this study, the influence of the depth and type of geogrid were investigated. The test results show that the triangular aperture geogrid performed better when placed at the depth of 1/3 of the plate diameter. Triangular aperture geogrids increased the load capacity and stiffness of the bases as compared with the unreinforced base.

1 INTRODUCTION

Being a planar reinforcement, geogrids have been successfully used to improve soft subgrade and reinforce base courses by providing lateral confinement. Biaxial geogrids are manufactured to have ribs in two orthogonal directions. The resulting geogrid apertures are either square or rectangular. Due to the shape of apertures, biaxial geogrids are relatively strong in the machine and cross-machine directions; however, they are relatively weaker in other directions (for example, 45^o to the machine direction). The numerical study done by Dong et al. (2010) demonstrated such a strength distribution. The new triangular aperture geogrid products with a triangular aperture shape just introduced into the market are expected to have a more stable grid structure, which can provide more uniform resistance in all directions. Similar to biaxial geogrids, triangular aperture geogrids are manufactured from a punched polypropylene sheet and then oriented in three equilateral directions so that the resulted ribs have a high degree of molecular orientation, which continues through the mass of the integral node. As a new product just introduced into the market, limited test data have been published so far on their behavior when used in the reinforced bases. Therefore, tests are needed to evaluate their behavior and mechanisms when used in the reinforced bases.

This paper discusses the results of plate load tests conducted to evaluate the improvement of bearing capacity and stiffness of triangular aperture geogrid-reinforced sand. Experiential tests were performed in this study to evaluate the triangular aperture geogrid-reinforced Kansas River sand under static loading. Unreinforced sand was also tested for the comparison purpose.

2 PAST STUDY ON BIAXIALGEOGRID REINFORCEMENT

Many studies have been done in the past on the use of biaxial geogrid as reinforcement. Mandal and Sah (1992) conducted model tests to evaluate the improvement in bearing capacity of soils reinforced by biaxial geogrids. Guido et al. (1987) and DeMerchant et al. (2002) performed a series of plate load tests to study the effects of several factors on the bearing capacity of biaxial geogrid-reinforced foundations. Gabr et al. (1998) conducted five plate load tests to investigate the stress distributions within the biaxial geogrid-reinforced sand at different depths. Gabr and Hart (2000) reported the results of nine plate load tests on biaxial geogrid-reinforced sand in terms of their elastic moduli. Alawaji (2005) studied the effects of creep and rate of loading on biaxial geogrid-reinforced sand using model plate load tests. Giroud and Han (2004a, 2004b) present a design method for biaxial geogrid-reinforced unpaved roads.

3 CURRENT STUDY

The objective of this study was to evaluate the triangular aperture geogrid-reinforced sand under static loading. This paper presents the results of six plate load tests performed on triangular aperture geogrid-reinforced bases. The variables studied in this research included: depth and type of geogrid. The behavior of the reinforced sand with a single layer of triangular aperture geogrid under static loading was investigated.

4 MATERIAL AND EQUIPMENT

4.1 *Granular Base Material*

Kansas River sand used as the granular base in this study is a poorly-graded sub-rounded river sand with a mean particle size (d_{50}) of 2.6 mm. The key properties of this sand are: maximum void ratio, e_{max}=0.583; minimum void ratio, e_{min}=0.3; coefficient of curvature, C_c=0.98; coefficient of uniformity, C_u=2.73; specific gravity at 20°C, G_s=2.65; friction angle ϕ=41°; maximum unit weight of sand, γ_{max}=19.5 kN/m^3; and minimum unit weight of sand γ_{min}=16.4 kN/m^3.

4.2 *Geogrid Types and Characteristics*

Three types of triangular aperture geogrid were used in this study. All the geogrids used for the tests were made of polypropylene. The properties of these triangular aperture geogrids are summarized in Table 1. The size of the geogrids used in the tests was 80cm in length by 80cm in width. Among these three products, Type I geogrid is the lightest one while Type III geogrid is the heaviest one.

Table 1. Properties of triangular aperture geogrid

Type	I	II	III
Nodal thickness (mm)	2.1	3.1	4.1
Junction efficiency (%)	100	100	100
Radial stiffness at low strain (kN/m@0.5% strain)	NA	430	475

4.3 *Test Setup*

The plate load tests were conducted in a medium-scale loading apparatus designed and fabricated at Department of Civil, Environmental, and Architectural Engineering at the University of Kansas. The loading plate was 15 cm in diameter. The loading system had an air cylinder of the same diameter as the loading plate and could apply a pressure up to 1,000kPa. Figure 1 shows the details of the loading system and the test box, which was square and had a plan area of 80×80 cm^2 with an adjustable depth. The Kansas River sand was placed into the box and compacted to 70% relative density by four layers, 5 cm each for all the four layers. 70% relative density of the sand was maintained in all tests. No subgrade existed for all the tests because the primary purpose of this research was to evaluate the behavior of the triangular aperture geogrid-reinforced bases under static loading. Tests were performed on both reinforced and unreinforced sections by increasing the load until failure. The load was applied through the air cylinder and the displacements were measured by three dial gauges. All the tests were run using a load controlling method. Next load increment was applied when no further displacement was noticed under the current load increment. The test was terminated when the total displacement became excessive (mostly greater than 20mm).

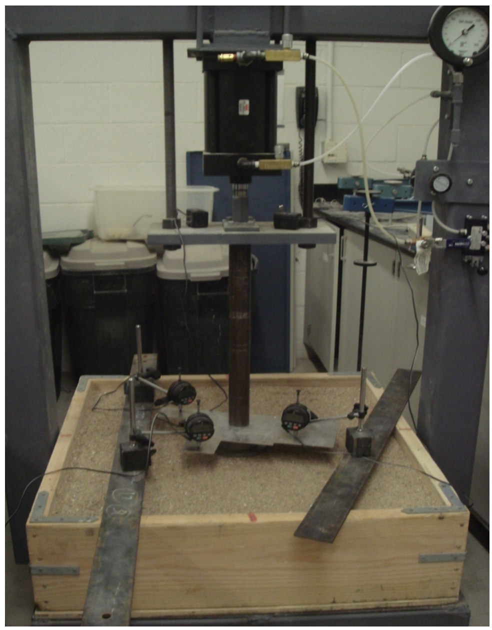

Figure 1 Test box and equipment

5 RESULTS AND DISCUSSIONS

5.1 *Effect of Geogrid Depth*

To study the effect of the top distance to the geogrid layer, the Type II geogrid was placed at a different position (5, 10, or 15 cm) in the Kansas River sand in each test. The test results of three reinforced sections and one unreinforced section are summarized in Figure 2. Figure 2 shows that the ultimate bearing capacity and stiffness (the slope of the initial portion) of the base decreased with an increase of the depth of the geogrid layer. When the triangular aperture geogrid was placed at the depth of 15cm (i.e., equal to the width of the plate width), it showed little improvement from the unreinforced base. The geogrid performed best when it was placed at the depth of 5cm, which is equivalent to 1/3 the plate width.

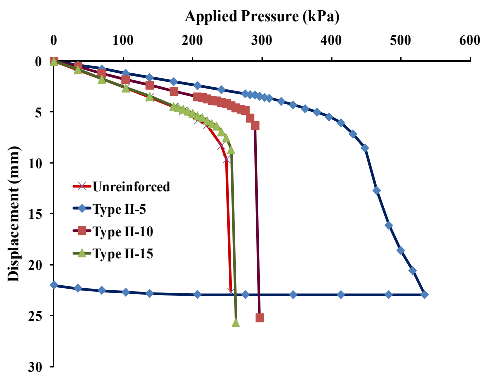

Figure 2 Pressure vs. displacement curves for unreinforced and reinforced bases by Type II triangular aperture geogrids at different depths

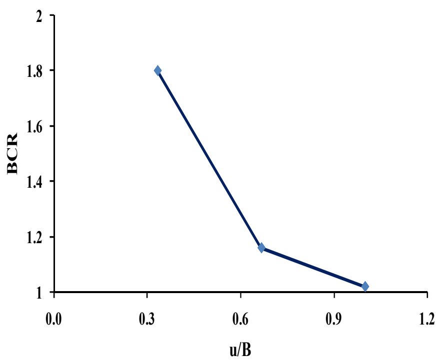

Figure 3 Bearing capacity ratio vs. depth-width ratio

Figure 3 presents the effect of the depth-width ratio on the bearing capacity ratio (BCR). BCR is defined as the ratio of the ultimate bearing capacity of the reinforced section to that of the unreinforced section. The depth-width ratio is defined as the ratio of the geogrid depth (u) to the width of the plate (B). It is shown that the BCR decreased from 1.8 to 1.0 with an increase of the u/B ratio and the largest BCR was at u/B equal to 1/3.

5.2 *Effect of Geogrid Type*

To investigate the effect of triangular aperture geogrid type on the bearing capacity and stiffness of reinforced bases, plate loading tests were carried out using three types of triangular aperture geogrid. The triangular aperture geogrid was placed at 5cm below the surface for each test on the reinforced base. An unreinforced base was also tested for the comparison purpose. Figure 4 presents the test results of three reinforced bases and one unreinforced base. It is shown that the inclusion of the triangular aperture geogrid increased the ultimate bearing capacity and stiffness of the reinforced base as compared with the unreinforced base. Figure 4 also shows that the ultimate bearing capacity and stiffness of the reinforced bases increased with an increase of the geogrid strength from Types I, II to III. For all tests, the geogrid-reinforced sand yielded at a displacement ranging from 5 to 10mm. For all the tests on the reinforced bases, no significant heaving was observed. This phenomenon indicated that the failure of these reinforced bases was due to the failure of sand below the geogrid because the geogrid minimized the heaving from that below.

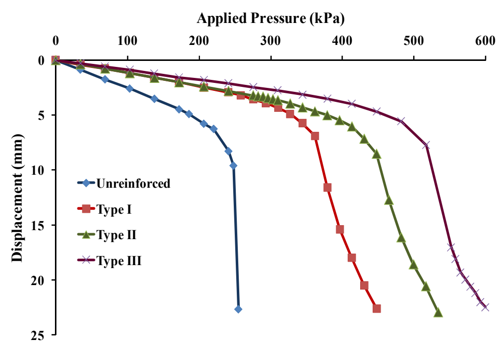

Figure 4 Pressure vs. displacement curves for unreinforced and reinforced bases with different types of triangular aperture geogrid

The elastic modulus of a base can be back-calculated using the following elastic solution:

$$\delta = pBI(1 - \nu^2)/E$$

where δ = displacement of the plate, p = pressure on the plate, B = diameter of the plate, I = displacement influence factor, ν = Poisson's ratio, and E = elastic modulus of the base.

Since the box was bounded by a firm foundation, the solution for a limited depth foundation in Harr (1966) was used to determine the displacement influence factor, I. Using the depth of the sand base at 20cm, the diameter of the loading plate of 15cm, the displacement influence factor I is 0.75. Assume Possion's ratio, ν, equals to 0.3. The elastic modulus of the reinforced or unreinforced base was calculated using the initial linear portion of the curve in Figure 4. The back-calculated elastic moduli of these bases are listed in Table 2. The elastic modulus ratio of the reinforced to unreinforced base was also calculated and summarized in Table 2. It is shown that the triangular aperture geogrid increased the elastic modulus more than twice as compared with the unreinforced one. Such an increase in the modulus or stiffness would increase the layer coefficient of the base course in a pavement section. Larger plate load tests will be valuable to verify the improvement of the BCR and the modulus ratio from this study.

Table 2 Back-calculated Elastic moduli of unreinforced and reinforced bases

Type	Elastic modulus (MPa)	Elastic modulus ratio
Unreinforced	4.0	-
Type I	8.4	2.08
Type II	8.8	2.20
Type III	11.6	2.89

6 CONCLUSIONS

This paper presents the results of an experimental study conducted to investigate the behavior of triangular aperture geogrid-reinforced bases under static loading. The following conclusions can be drawn from this study:

- In all tests, the reinforced bases were found to perform better than the unreinforced bases.
- The benefit of the triangular aperture geogrid was most mobilized when it was placed at 1/3 the width of the loading plate. When the geogrid was placed deeper, the benefit decreased.
- The ultimate bearing capacity and stiffness of the triangular aperture geogrid-reinforced base depended on the type of the triangular aperture geogrid and increased with the strength of the geogrid.
- The triangular aperture geogrid increased the elastic modulus of the base more than twice as compared with the unreinforced one.

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