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Numerical analysis of tensile behavior of geogrids with rectangular and triangular apertures

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ABSTRACT

Geogrids, made of polymeric materials, have been used as a construction material for many applications, such as walls, slopes, roads, building foundations, etc. In the past, geogrids were manufactured with apertures in a rectangular or square shape. Recently, geogrids with a triangular aperture shape have been introduced into the market. The new geogrids are manufactured with ribs oriented in three equilateral directions and expected to have a more stable grid structure, which can provide more uniform resistance in all directions. In this study, the numerical software – FLAC was adopted to investigate the responses of geogrids with rectangular and triangular apertures when subjected to a uniaxial tensile load at different directions relative to the orientations of ribs in air. The geogrid ribs were modeled using beam elements jointed rigidly at nodes (i.e., the angle between two adjacent ribs did not change) and subjected to tension in one direction. The numerical results showed that the stress–strain responses of the geogrids were different at different loading directions relative to the orientations of ribs. The effects of aperture shape of geogrid, and elastic modulus and cross-section area of geogrid ribs on the tensile stiffness of the geogrid were also evaluated. The geogrid with triangular apertures had more uniform tensile stiffness and strength distributions than the geogrid with rectangular apertures. An increase of the elastic modulus and cross-section area of the geogrid ribs could increase the stiffness of the geogrid with triangular apertures. The numerical results were verified by experimental data for geogrids with rectangular and triangular apertures.

1. Introduction

Geogrids are made of polymeric materials (mostly high-density polyethylene, polypropylene, or polyester) with a different manufacturing process (extruded and punched-drawn, knitting, or welding). Details of the geogrid manufacturing can be found in the textbook by Koerner (2005). The geogrid manufactured by the extruded and punched-drawn process is unitized and has rigid joints at nodes (i.e., the angle between two adjacent ribs does not change during loading) due to much larger thickness at nodes than ribs. The extruded and punched-drawn geogrids will be investigated in this study. In the past, geogrids were manufactured with apertures in a rectangular or square shape. They are used to carry tensile force in one or two directions along the ribs. The geogrid with one-directional tensile strength is commonly referred to as uniaxial geogrid, which is mainly used for walls and slopes (for example, Han and Leshchinsky, 2010). The geogrid with two-directional tensile strengths is commonly referred to as biaxial geogrid, which is mainly used for roads, foundations, and pile-supported embankments. The use of geogrids has been increasing steadily over the past 30 years and is expected to continue to rise.

Recently, geogrids with a triangular aperture shape have been introduced into the market. The new geogrids are manufactured with ribs oriented in three equilateral directions and expected to have a more stable grid structure, which can provide more uniform resistance in all directions. The geogrid with triangular apertures is expected to be used in the similar applications as biaxial geogrids especially when the loading is not only in two directions. Fig. 1 shows the products of the geogrids with rectangular and triangular apertures.

The uses of biaxial geogrids for subgrade improvement, base and ballast reinforcement, foundation reinforcement, and pile-supported embankments have been studied by many researchers, for example,

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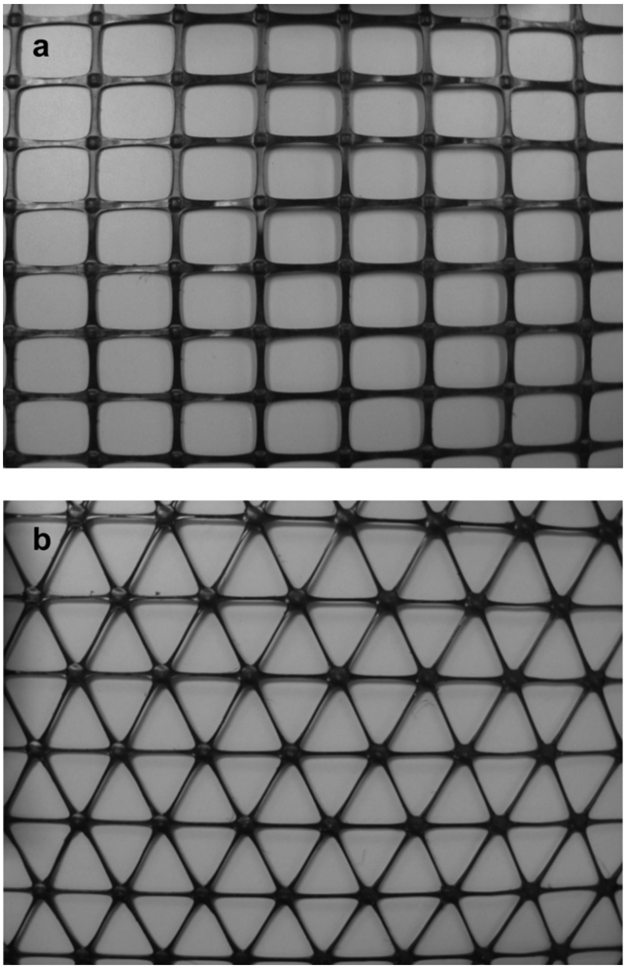

Fig. 1. Extruded and punched-drawn products of geogrids with rectangular and triangular apertures. (a) Geogrid with rectangular apertures, (b) Geogrid with triangular apertures.

Abdullah and Edil (2007), Adams and Collin (1997), Brown et al. (2007), Gailer (1987), Han and Akins (2002), Helstrom et al. (2006), Huang and Han (2009), Kinney et al. (1998), and Tang et al. (2008). Also, the behavior of biaxial geogrid-reinforced earth structures has been studied through field full-scale tests, laboratory model tests, and numerical simulation, for example, Abu-Farsakh et al. (2008), Sugimoto and Alagiyawanna (2003), and Viswanadham and KÖnig (2004). Guido et al. (1987) and DeMerchant et al. (2002) conducted a series of plate load tests to study the effects of several factors on the bearing capacity and stiffness of biaxial geogrid-reinforced aggregate beds. Gabr and Hart (2000) reported several model tests on biaxial geogrid-reinforced sand in terms of their elastic moduli. Giroud and Han (2004a, 2004b) presented a design method for biaxial geogrid-reinforced unpaved roads. Dong et al. (2010a) conducted a numerical investigation into the stress–strain responses of biaxial geogrids under uniaxial tension at different directions relative to the orientations of ribs. This study demonstrated the non-uniform distributions of tensile stiffness and strength of the biaxial geogrids for a specific geogrid product. Additional analyses were conducted in this study for biaxial geogrids.

The new geogrid products with triangular apertures recently introduced into the market are expected to have a more stable grid structure, which can provide more uniform resistance in all directions. However, limited test data related to the geogrids with triangular apertures have been published so far. Dong et al. (2010b) conducted six plate load tests to study the influence of the depth and type of the geogrids with triangular apertures on the reinforced sand bases. The effects of aperture shape, depth, and number of geogrids on the bearing capacity were investigated by Dong et al. (2010c). Dong et al. (2010c) found that the geogrid with triangular apertures was more efficient than that with rectangular apertures in terms of the ratio of the ultimate bearing capacity to the mass of the geogrid.

In this study, a numerical method was adopted to investigate the behavior of the geogrids with triangular apertures under uniaxial loading at different loading direction relative to the orientation of ribs. The reason for selecting a uniaxial loading test is that this test is the most common method to evaluate the stress–strain behavior of geosynthetics. In field, geosynthetics may be subjected to biaxial or multi-axial loading. The study on biaxial loading of geogrids is under way and will be presented in a future publication. The biaxial geogrid was also modeled for the comparison purpose. To be consistent with the terminology of the geogrid with triangular apertures, the term "geogrid with rectangular apertures" is used hereafter in this paper instead of the "biaxial geogrid". This paper presents the effect of the loading direction relative to the orientation of ribs on the stress–strain responses of the geogrids with rectangular and triangular apertures. In addition to the loading direction, this study studied the influence of the following factors on the tensile stiffness of the geogrids: aperture shape of geogrid, and elastic modulus and cross-section area of geogrid ribs.

2. Numerical modeling

The finite difference software – FLAC (Fast Lagrangian Analysis of Continua) 2D program Version 5.0 was adopted in this study to investigate the behavior of the geogrids with rectangular and triangular apertures under tension at different directions relative to the orientation of ribs. FLAC 2D has been successfully used by many researchers to study geotechnical problems, for example, Han and Gabr (2002) and Huang et al. (2009). Han and Gabr (2002) numerically investigated geosynthetic-reinforced fill platforms over pile foundations. In the Han and Gabr (2002) study, the geosynthetic reinforcement was modeled using solid elements. Huang et al. (2009) studied geosynthetic-reinforced column-supported embankments over soft soil using mechanically and hydraulically coupled models. In the Huang et al. (2009) study, the geosynthetic reinforcement was modeled using cable elements. FLAC models materials using solid elements in zones and/or structures elements in segments. The numerical results can include stresses and strains in each zone, displacements on each node, and axial force in each element, etc.

2.1. Model considerations

Beam elements, which can have bending stiffness and rigid connections at nodes, were used in this study to represent extruded and punched-drawn geogrids. Beam elements were jointed rigidly at nodes (i.e., the angle between two adjacent ribs at each node was maintained the same during the tensile test) to form apertures and a geogrid sheet. All the ribs were modeled as a linearly elastic-perfectly plastic material. Considering possible large deformation of a geogrid sample, a large-strain mode was chosen for the analysis.

To model a geogrid sample subjected to a uniaxial tensile load at a different direction relative to the orientation of ribs, the geogrid sheet was rotated around a fixed centroid to a desired angle (0, 45, 60, and 90°), cut into the dimension required for a wide width tensile test, and then subjected to a horizontal uniaxial tensile force. Based on ASTM D6637-01, the minimum size of the geogrid