The Biaxial Load-Strain Behaviour of Biaxial Geogrids

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ABSTRACT: Technical assessments of structures reinforced with biaxial geogrids with integral or welded junctions in the field or laboratory, have consistently indicated much lower strain development in the geogrids than can be reasonably predicted by conventional or finite element analysis. It appears that biaxial geogrids exhibit much higher stiffness when acting under biaxial operational load/strain conditions than under uniaxial laboratory testing conditions. For this reason, ‘in-isolation’ biaxial testing of these materials has been undertaken on three biaxial geogrids with integral or welded junctions. Test results are presented.

1 INTRODUCTION

Polymeric geogrids are being used in an increasing number of civil engineering and environmental protection applications. They are produced in a variety of geometrical forms using a wide range of polymeric materials and numerous manufacturing techniques. However, two classes of geogrid reinforcements may be identified; uniaxial geogrids, which develop tensile stiffness and strength primarily in one direction, and biaxial geogrids which, develop tensile stiffness and strength in two orthogonal directions, the test methodologies employed to characterise the load-strain-time properties of geogrids have involved the application of uniaxial loading, BS 6906 (1987), GRI-GG4 (1987), ISO 13431 (1999), ISO 10319 (1999), ASTM D5262 (2002). For biaxial geogrids this has generally involved undertaking two separate tests in orthogonal directions. Attempts to combine the measured properties in these two directions in order to obtain the overall biaxial properties/behaviour of the geogrids have proven to be problematic, McGown & Kupec (2004). In this paper, the basic behavioural differences of various forms of geogrids are related to their applications. Details are given of the development of an ‘in-isolation’, (i.e. tested in-air and not in-soil), biaxial loading method for biaxial geogrids with welded and integral junctions. Test data obtained from short-term sustained biaxial loading tests are presented.

2 GEOGRID TYPES

The load-strain behaviour of geogrids may vary significantly in the two axes of principal stiffness. This is often associated with variations in the material and geometrical properties of bars and junctions in these directions, Fig. 1.

2.1 Uniaxial Geogrids

Uniaxial geogrids usually exhibit a high stiffness in the machine direction [MD] with a very low to negligible stiffness in cross-machine direction [XMD], however, it should be noted that there are products which have their maximum properties in the XMD. The main functions of the secondary cross-members and junctions are principally to provide geometrical stability during transport and installation, but they may also provide the possibility of interlock with the soil in which they are placed.

These uniaxial geogrids are intended for use in plane strain applications, where the secondary direction has little or no tensile loading, i.e. plane strain applications. Some design codes or methods suggest/specify that two layers of uniaxial geogrids should be laid orthogonally in order to resist biaxial loading, e.g. BS 8006 (1995), EBGEO (1997).
2.2 Biaxial Geogrids

Biaxial geogrids exhibit significant stiffness and strength in two orthogonal directions. In these materials, the bars and junctions provide geometrical stability during transport and installation and almost always provide interlock with the soil in which they are placed.

2.2.1 Anisotropic Biaxial Geogrids

Anisotropic geogrids exhibit dissimilar stiffnesses in the two principal directions. They are used in anisotropic loading conditions, i.e. where there is both a primary and secondary degree of loading /strain.

2.2.2 Isotropic Biaxial Geogrids

Isotropic biaxial geogrids exhibit very similar stiffnesses and strengths in two orthogonal directions. They are used in isotropic loading conditions, i.e. where there is almost an equal degree of loading/strain in two orthogonal directions.

3 GEOGRID FUNCTIONS

It is important to relate the material properties of reinforcing products to their performance requirements under operational conditions, i.e. to identify both the Serviceability Limit State and the Ultimate Limit State requirements, in-soil behaviours.

Test methods for uniaxial geogrids are well established and are currently employed to test biaxial geogrids. Short-term properties may be determined by a wide range of ‘Index’ tests, which produce a broad range of quality control properties, e.g. Constant Rate of Strain [CRS] tests provide short-term stiffness and strength properties. Long-term properties may be determined by established ‘Performance’ tests and are used in designs, e.g. sustained loading (creep) tests and stress relaxation tests provide long-term stiffness and strength properties. It has to be highlighted that the above properties are determined in a uniaxial manner, hence for biaxial geogrids two specimens are tested in orthogonal directions.

Thus at the present time, uniaxial geogrids and anisotropic or isotropic biaxial geogrids are all tested in a very similar manner ‘in-isolation’ or ‘in-soil’ as test conditions for biaxial geogrids are identical to those employed in uniaxial geogrid testing, the biaxial nature of biaxial geogrids is largely being ignored. It is therefore suggested that a new approach to the testing of biaxial geogrids is required in order to determine their biaxial load-strain behaviour.

4 LOAD-STRAIN TESTING OF BIAXIAL GEOGRIDS

Various forms of biaxial short-term and long-term load testing of geosynthetics have been undertaken previously and most have suffered specimen distortion into non-orthogonal shapes, non-uniform stressing particularly at the junctions, premature specimen rupture and/or problems with clamping of the specimens, Böhmert (1981), Bush & Böhmert (1992) and Nimmesgern (1994), Saathof (1997). However, in other engineering disciplines, biaxial loading test methods have been developed and proven to be capable of establishing the properties of biaxial products without the difficulties experienced in the testing of geosynthetics, e.g. Krause & Bartolotta (2001) and Bridgens & Gosling (2003) as illustrated in Fig. 2.

Using the knowledge gained from biaxial testing in other disciplines, a new approach to testing biaxial geogrids is presented in this paper. In particular details are given of test specimen sizes and shapes, clamping arrangements, and test methodology.

4.1 Material used for Biaxial Load Testing of Biaxial Geogrids

The properties and geometry of the biaxial geogrids tested are described in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Per Unit Area</td>
<td>580</td>
<td>370</td>
<td>560</td>
</tr>
<tr>
<td>Polymer Composition</td>
<td>PP</td>
<td>PP</td>
<td>PET</td>
</tr>
<tr>
<td>Molecular State</td>
<td>Varies from random to oriented (Amorph to Semi-Crystalline)</td>
<td>Highly oriented (Semi-Crystalline)</td>
<td>Highly oriented (Semi-Crystalline)</td>
</tr>
<tr>
<td>Junctions</td>
<td>Integral</td>
<td>Welded</td>
<td>Welded</td>
</tr>
<tr>
<td>Macro Structure</td>
<td>Biaxially stretched</td>
<td>Welded pre-stretched monolithic flat bars</td>
<td>Welded pre-stretched monolithic flat bars</td>
</tr>
<tr>
<td>Short-term Nominal Strength*</td>
<td>40 / 40</td>
<td>60 / 60</td>
<td>60 / 60</td>
</tr>
</tbody>
</table>

*Manufacturer’s specification
Figure 1. Types of geogrids

- **UNIAXIAL**
  - Essentially uniaxial load-strain-time behaviour
  - Secondary direction stiffness very low or negligible

- **BIAXIAL**
  - Anisotropic load-strain-time behaviour
  - MD ≠ XMD
  - MD and XMD exhibit dissimilar stiffnesses

- **ANISOTROPIC**
  - Isotropic load-strain-time behaviour
  - MD = XMD
  - MD and XMD exhibit very similar stiffnesses

- **ISOTROPIC**
  - Essentially uniaxial load-strain-time behaviour
  - Secondary direction stiffness very low or negligible

Figure 2. Biaxial test apparatus for high-strength fabrics, after NASA – Krause & Bartolotta (2001)

(a) Geogrid with integral junctions

(b) Geogrid with welded junctions

Figure 3. Typical cruciform biaxial test specimens for biaxial geogrids
4.2 Specimen Sizes

Cruciform shaped test specimens, similar to those employed in other disciplines were used in order to avoid problems reported in earlier work with square or rectangular specimens. The cruciform shape prevents the distortion of the test specimen at higher strain levels and avoids the problem associated with non-uniform stress conditions.

Representative geogrid sample sizes incorporating at least 5 bars in each direction and so 25 junctions were selected to represent the grid behaviour. The central biaxial test specimen size was between 100 and 220 mm square, with an overall cruciform specimen dimensions of some 500 x 500 mm, Fig. 3.

4.3 Test Methodology

Test results from biaxial ‘in-isolation’ CRS ‘Index’ tests were reported by McGown & Kupec (2004). This paper seeks to determine long-term material properties that may be used in designs. It is suggested that the ‘in-isolation’ and ‘in-soil’ behaviour of the materials reported in this paper are very similar, therefore the uniaxial sustained loading tests were carried out strictly according to existing standards, i.e. BS6906-Part 5 (1991), ISO 13431 (1999), in the biaxial creep test apparatus to determine if differences between test apparatuses existed. In fact, the differences measured were negligible; hence all subsequent sustained loading tests were conducted in the biaxial creep test rig, Fig. 4.

The biaxial sustained loading (creep) testing was undertaken with the identical clamping arrangements used in standard uniaxial sustained loading (creep) tests. The sustained loads in the two orthogonal directions, were applied in an isotropic manner, i.e. the loads in both directions were equal. This is not a requirement of the test procedure, anisotropic loads may be applied. However, no matter what loads are applied they must be applied in both directions at the same time.

The sustained loads were thus applied simultaneously at the beginning of the test. Subsequently they were removed at the end of the test, again simultaneously, in order to observe the elastic (time independent) strain upon unloading and then the time dependent recovery strains. The sustained loads in each direction were varied between 10 and 50 percent of the nominal short-term tensile strength obtained from uniaxial (Index) testing conducted according to BS 6906 (1991). At least three tests were conducted at sustained load levels equal to 30 percent of short-term loading to determine the specimen variation. The specimen variation was within 95% confidence limits and all subsequent tests were carried out once only. All loads were applied for at least 100 hours and after unloading the specimen was observed for further 100 hours to determine any recovery over time. The tests were carried out under a controlled atmosphere of 20 ± 2°C and 65% relative humidity.

Deformation measurement was conducted by using a 2MPixel digital camera which achieved a post-processing accuracy of ±100µm using software developed for the camera and National Instruments IMAQ® Vision.

5 TEST RESULTS

Uniaxial and biaxial sustained loading test results for geogrids A, B and C at load levels from 10 to 50 percent of nominal strength are presented in Figs. 5 to 7. The test results obtained at 30 and 50 percent nominal strength are highlighted to ease the interpretation of test data and enable comparisons to be made.
Figure 5. Uniaxial and biaxial sustained loading (creep) test results – geogrid A [PP]
a) Uniaxial sustained loading (creep) test results

b) Biaxial sustained loading (creep) test results

c) Comparison of uniaxial and biaxial sustained loading test results at 30 and 50% nominal strength

Figure 6. Uniaxial and biaxial sustained loading (creep) test results – geogrid B [PP]
a) Uniaxial sustained loading (creep) test results

b) Biaxial sustained loading (creep) test results

c) Comparison of uniaxial and biaxial sustained loading test results at 30 and 50% nominal strength

Figure 7. Uniaxial and biaxial sustained loading (creep) test results – geogrid C [PET]
6 INTERPRETATION OF TEST RESULTS

The strain against log.time plots for geogrids A, B and C with integral or welded junctions indicated increased stiffness for specimens tested biaxially over those tested uniaxially.

What can be observed is that there are significant changes in the initial, i.e. elastic, strain upon loading. Furthermore, geogrid A exhibits changes in the time dependent strains developed under sustained loading due to creep of the material. It is therefore suggested that changes in behaviour under biaxial loading may be twofold; firstly there may be changes in the initial strains and secondly there may be changes in the creep rate developed with time. In each case the biaxially loaded behaviour of biaxial geogrids is characterised by significantly greater stiffness at any time after loading.

7 DISCUSSION & CONCLUSIONS

The tests show that geogrids with integral or welded junctions develop significantly higher stiffnesses under 'in-isolation' biaxial loadings. These changes in stiffness may be expressed as ratios of biaxial to uniaxial initial strains and ratios of biaxial to uniaxial strains developed during sustained loading.

It is suggested that the Isochronous Strain Energy approach may be used to combine the test data obtained from biaxial testing, as strain energy is a scalar quantity and not a vector quantity. The applications of this approach are many, as indicated in previous work by McGown (2000).

Wovens and geonets are likely to reflect similar differences if they have entangled junctions and are tested ‘in-soil’. It is therefore required to undertake ‘in-soil’ biaxial testing to determine any differences for such woven and geonet materials with entangled junctions.

Lastly, it is suggested that the increase in biaxial stiffness may be directly related to the behaviour of junctions under tensile stresses or strains in the principal, orthogonal directions. The apparent increase in stiffness may be ascribed, to some degree, to the effect of ‘Poisson’s Ratio’ and to the re-orientation of the amorph molecules in the junction areas. This effect is discussed in more detail by Kupec et al (2004).

REFERENCES


GRI-GG4 1987: Determination of the Long-Term Design Strength of Stiff and Flexible Geogrids. Geotextile Research Institute, USA.


