The properties and performance of planar geogrids with integral junctions and ribs in three directions

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ABSTRACT: A new range of planar geogrids with integral junctions have been developed having ribs in three directions. These grids are produced from different thicknesses of punched sheets, which are stretched in a hot drawing process. Depending on the draw ratios applied they can be essentially isotropic or anisotropic in terms of their load-strain-time behaviour. The junctions comprise un-oriented polymer linked to the ribs of oriented polymer by short transition zones. The grid aperture size can be varied to suit the size and grading of the soil in which the grid will be placed. This ensures very efficient soil grid interaction is developed. The structure of these geogrids is unique and in order to assess their load-strain-time and interaction properties a detailed investigation has been undertaken. This required the careful selection of test specimen sizes and shapes, clamping arrangements and test methodologies. Additionally it was necessary to develop appropriate means of analysing and presenting test data for use in design methods related to the applications in which these geogrids would be employed. In this paper the loading conditions in the applications in which these new products may be employed are identified. The need to determine the one, two and three directional load-strain-time behaviours of the geogrids is highlighted, based on constant rate of deformation (CRS), sustained load (creep) and repeated loading (cyclic) in-plane testing as well as out-of-plane plate load test data.

1 INTRODUCTION

The use of geosynthetic materials in civil engineering has grown dramatically over the last 40 years. Throughout this period new types of geotextiles, geonets, geomeshes, goegrids and composite materials have been developed and introduced as soil reinforcements. Testing procedures, methods of analysing and presenting test data and appropriate design techniques have had to be developed to suit the particular characteristics of these materials and their performance requirements in various types of reinforcing applications.

Most recently a new type of planar geogrid with integral junctions and stretched ribs in three directions has been developed, Tensar® TriAx®. It is intended that this new geogrid will be used in soil reinforcement, road pavements, loaded areas and railway track applications. In order to assess the properties of this tri-directional geogrid for quality control and design purposes, a careful selection of test specimen sizes and shapes, clamping arrangements and test methodologies has been necessary.

In this paper the tri-directional geogrids are described and the loading conditions in the applications in which these geogrids may be employed are identified. The need to measure the one, two and three directional load-strain-time behaviours of the geogrids is highlighted, based on constant rate of deformation (CRS), sustained (creep) loading and repeated (cyclic) loading.

2 BACKGROUND

The problems associated with variations in Manufacturers Quality Control testing regimes led Specifiers and End-users to demand the development of standardised Quality Control testing regimes. Therefore, from the late 1970's onwards, National and then International Test Methods / Standards were developed and introduced. These standardised Quality Control test methods specify test conditions, clamping techniques, test specimen shapes and sizes, methods of load application and the methods of analysing and presenting the test data and are often termed *Index tests,* (Murray and McGown, 1982).

In the early stages of the use of geosynthetic reinforcing materials, many design methods were developed which were empirically based. Index test data were used to represent the material properties of the geosynthetics. In most situations these empirical design methods produced satisfactory, if conservative, design solutions.

In the 1980's more fundamentally based designs and back-analysis methods for Geosynthetic Reinforced Soil Structures were introduced and the need to obtain representative material properties for geosynthetics became more and more necessary. This involved developing test regimes which more closely represented the operational load-strain-time-temperature conditions in the applications in which the geosynthetics were employed. Such tests have been termed *Performance Tests,* (Murray and McGown, 1982). Given the diverse range of reinforcement applications and site conditions, there cannot be a single Standard Performance test method, rather there must be a number of different types of Performance test methods which are related to different specific application requirements.

With all of the above in mind, the development of appropriate test methods for the assessment of the new type of geogrid has been carefully undertaken in the manner described in the following sections.

3 DESCRIPTION OF GEOGRIDS

Until recently, geogrids could be divided into two groups, viz. *Uniaxial* and *Biaxial* geogrids, (McGown and Kupec, 2008). Uniaxial geogrids were defined as those which exhibit a high degree of stiffness and strength in one direction only. Biaxial geogrids were defined as those with significant strength in two orthogonal directions. Biaxial geogrids which have the same or very similar properties in the two directions are described as *Isotropic,* whereas those with significantly different properties in the two directions were described as *Anisotropic.*

The new range of tri-directional geogrids are formed with integral junctions and ribs in three directions, oriented at 60^0 to each other. They are produced from different thicknesses of sheets of polymer, which are punched and stretched in a hot drawing process. Depending on the draw ratios employed, they can be produced to be essentially isotropic or somewhat anisotropic in terms of the stiffness and strength. The junctions so produced consist largely of un-oriented polymer linked to ribs of oriented polymer by short transition zones, Fig.1. The grid aperture sizes can be varied to suit the size and grading of the soil in which the geogrid is to be embedded in order to achieve the maximum interlock.

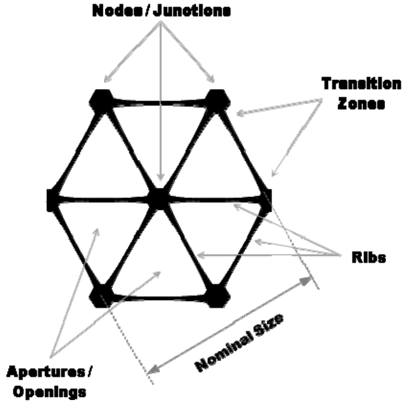

Figure 1 Definitions of the structural features of the tri-directional geogrid.

The various orientation / directions in the tri-directional geogrid structure are defined as shown in Fig.2.

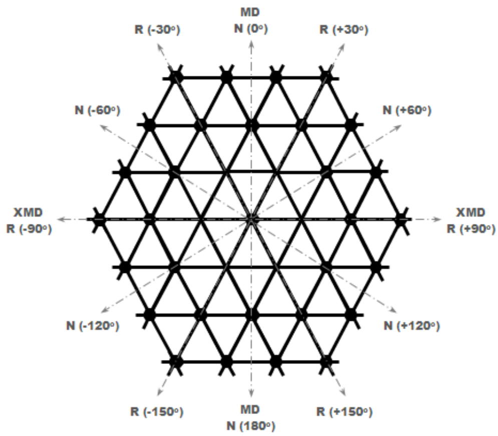

Figure 2 Definition of the various orientations / directions in the tri-directional geogrid.

4 QUALITY CONTROL TESTING

Specifiers and End-users should use the International Standard Wide Width test procedure, (ISO 10319, 1993), in a manner similar to that adopted for the Quality Control of uniaxial and biaxial geogrids. The choice of clamping arrangement and test specimen size and shape are, however, important and it may be decided that testing in at least three different directions is appropriate.

5 PERFORMANCE TESTING

The new tri-directional geogrids may be used in applications where plane strain conditions exist. Thus in the same manner as uniaxial or biaxial geogrids they will be subject to uniaxial loading conditions. Hence it is important to determine the uniaxial properties of these tri-directional geogrids using standardized test procedures developed for uniaxial geogrids, (McGown et al, 1985), but with suitably modified clamping arrangements and test specimen sizes and shapes.

Additionally they may be subjected to biaxial loading conditions in some applications and so it is important to determine the biaxial properties of these materials using an appropriate biaxial geogrid test procedure, (McGown and Kupec, 2004 and Brown et al, 2007). Again the choice of clamping arrangement and test specimen size and shape are important.

However, the new tri-directional geogrids can be used in applications where there is axi-symmetrical loading applied or at least significant three directional loading. In these conditions a new approach to the axi-symmetric Performance testing of these materials requires to be developed.

6 AXI-SYMMETRIC TESTING

6.1 *Out-of-plane plate loading testing*

For applications where axi-symmetric loading applies then the tri-directional geogrid requires to be subject to an axi-symmetric loading regime. Out-of-plane plate loading tests provides such a loading regime.

The test equipment was originally developed to test biaxial geogrids, (Kupec, 2004), but was significantly modified to allow testing of the tri-directional geogrids.

A steel portal frame was added, which was fixed above and across the centre of the test rig to support an hydraulic actuator. The actuator applied load onto the loading platen, which is a rigid 300mm diameter plate with a roughed base. Loads can be applied with the platen moving at a constant rate of deformation or as a sustained load or as a repeated load.

The test sample was clamped along the four edges of the test frame but was vertically supported by a further rigid internal plate to provide an unsupported central test section of 950mm diameter, Fig.3.

To measure vertical displacements, a displacement transducer was placed on the loading platen and several others on the test specimen at various points between the edge of the platen and the outer edge of the test specimen. To measure the radial and circumferential displacements in the test specimen, a

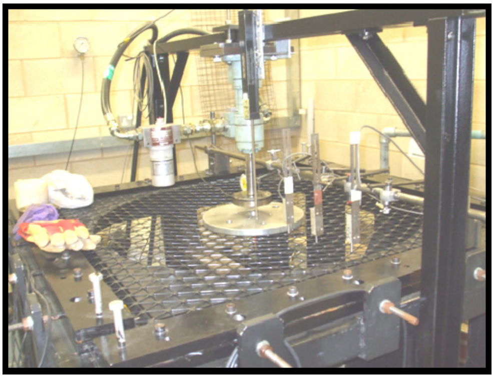

Figure 3 The out-of-plane plate loading test apparatus

digital photogrammetric technique was used. This technique was a development of that used by Kupec (2004) and involved the acquisition and analysis of a series of digital images taken at regular intervals as each test proceeded.

Thus for each test the central load and vertical, radial and circumferential displacements were recorded. This allowed the relationship between vertical load applied and the loads developed radially at specific points within the test specimen to be calculated. Using the various displacement data, the radial strains were calculated at the same points where the radial loads in the test specimen were known. In this way the “overall” and “local” radial load-strain relationships were determined. This allowed the “overall” and “local” radial stiffnesses and strengths of the test specimen to be determined. In fact the “overall” values are a function of the test specimen size and shape, however, the “local” stiffnesses and strengths are fundamental properties of the material. Thus by carrying out tests at a constant rate of deformation, with sustained loads and with repeated loads, this test can provide the axi-symmetric radial stiffness and strengths of the tri-directional geogrid when subject to axi-symmetric loading conditions.

However, the test apparatus and methodology is complex, therefore, an alternative, simpler test methodology was developed, which was based on in-plane testing of segmental test specimens.

6.2 *In-plane testing of segmental test specimens*

The circular test specimen used in the out-of-plane tests may be represented by six, equal 60^0 segments. These may be formed in two ways, either centred across the directions of the ribs or centred along the directions of the ribs, as shown in Fig.4.

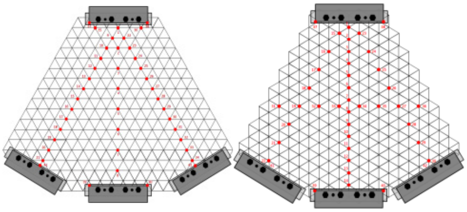

Figure 4. The two types of segmental test specimens

Segmental test specimens taken at different orientations with respect to the Machine Direction, see Fig.2., were mounted vertically in a tensile load test machine and clamped as shown in Fig.5. The lower three clamps were fixed and the tensile loads applied at the top single clamp.

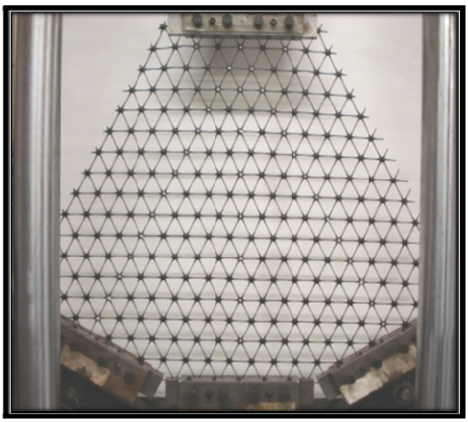

Figure 5. The segmental test specimen under load in the tensile test machine.

The applied loads and "overall" and "local" radial deformations were recorded in the same manner as in the out-of-plane tests. With the assumption of uniform load distribution within the test specimens, the "overall" and "local" stiffnesses and strengths could be calculated for these segmental test specimens tested with loads applied under a constant rate of loading, with sustained loads and with repeated loads.

6.3 *Comparison of out-of-plane and in-plane test data*

For each of the two types of segmental test specimens tested at different orientations with respect to the Machine Direction, the "local" load-strain behaviour of the material were compared to the "local" load-strain behaviour of the material from the out-of plane tests on circular test specimens. Differences were identified due to differences in the circumferential restraint acting in the various tests, but these were consistent differences. Thus the in-plane segmental test specimen data could be calibrated to match with the out-of plane test data. Further the "overall" in-plane segmental test data could be calibrated to the "local" in-plane test data thus allowing the digital photogrammtric measurements of "local" deformations to be omitted for routine testing.

7 DISCUSSION

Ongoing investigations of the Performance test properties of the new tri-directional geogrids are directed towards carefully establishing of *Test Calibration Factors* linking the axi-symmetric out-of plane and in-plane test data for both "overall" and "local" radial stiffnesses and strengths under constant rate of deformation (CRS), sustained (creep) and repeated (cyclic) loading conditions. These will allow the development of the in-plane segmental specimen test methods to determine data for the design and back-analysis of these new geogrids in applications where there is axi-symmetrical loading.
The properties of the tri-directional geogrids when acting under uniaxial and biaxial loading conditions are also being investigated using already established uniaxial and biaxial test methods.

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