JUNCTION STRENGTH TESTING FOR GEOGRIDS

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ABSTRACT: Geogrids are made from different polymers, have widely different dimensions, a range of load-strain behaviours and exhibit a large variety of junction forms, including entangled, heat bonded, welded and integral junctions. The junctions may have several functions, including maintaining the geometrical form of the structure during transport and installation; enabling stresses and strains to be transferred through the grid and developing interlocking stresses between the soil and the grid. The relative importance of these functions varies with the product type. Currently there are no recognised international or national standards or codes which set-out junction testing parameters, the only junction strength tests having been developed over two decades ago for the first generation of geogrids with integral junctions and they are not necessarily appropriate for all types of junctions now employed in geogrids. In this paper, the contribution of the tensile ribs and junctions to the load-strain behaviour of geogrids and to the soil-geogrid interaction processes are described. Existing and new test procedures to assess the quality control (Index) properties and the in-soil performance characteristics of geogrids are described. Recommendations are then made for quality control and in-soil design parameters to be used for the specification of geogrids.

1 INTRODUCTION

The first form of geosynthetic reinforcements were sheets and woven geotextiles, nets and meshes together with linear strips of polymeric fibres encased in a sheath, sometimes formed into a grid by weakly heat bonding them at cross-over points. In the late 1970's polymeric uniaxial and biaxial geogrids with integral junctions were first produced. These newly developed polymeric reinforcements found a wide range of applications in the construction industry. Inevitably, their success encouraged the development of a number of other forms of geogrids and these have been gradually introduced over the last two decades. However, in general terms, all geogrids may still be described as consisting of joint parallel sets of tensile ribs with apertures of sufficient size to allow strike through of the surrounding soil, stone, or other geotechnical material, Koerner (1999). In addition, they may be characterised in terms of the properties of their tensile ribs and junctions as well as their overall product behaviour.

The tensile ribs forming geogrids may lie in only one direction with much weaker connecting cross-members in the orthogonal direction, as in uniaxial geogrids. Alternatively they may have tensile ribs in the two orthogonal directions, both of which carry tensile load, as in biaxial geogrids. However, the tensile ribs in the two directions do not necessarily have the same load-strain behaviours, so that both isotropic and anisotropic biaxial geogrids may be produced. The tensile ribs may also be of relatively uniform cross-section, variable cross-section or consist of groups of aligned fibres or filaments.

The junction types now in use may consist of entangled fibres or filaments, of ribs heat bonded, laser, microwave or friction welded at cross-over points or have integral junctions formed during the uniaxial or biaxial drawing of punched sheets.

The resulting geogrid products manufactured from various combinations of the above types of tensile ribs and junctions represent a wide range of geosynthetic materials exhibiting uniaxial or biaxial load-strain characteristics, with biaxial products either isotropic or anisotropic. In addition, some rely entirely on the surface shear properties of the tensile ribs and junctions to interact with the surrounding soil whereas other rely on a combination of surface shear and bearing stresses on the cross-members or transverse ribs. Some geogrids have the ability to develop a dynamic interlock effect, McGown et al (1990) and McGown et al (1994).

In this paper, the contribution of the tensile ribs and junctions to the load-strain behaviour of geogrids and to the soil-geogrid interaction processes are described. Existing and new test procedures to assess the quality control (Index) properties and the in-soil Design (Performance) characteristics of geogrids are described. Recommendations are then made for quality control and in-soil design parameters to be used for the specification of geogrids.

2 THE BEHAVIOUR OF TENSILE RIBS

The aligned fibres or filaments and the ribs possessing uniform cross-sections and properties may be simply clamped and tested under Constant Rate of Strain [CRS], Sustained Loading (creep) or other test methodologies in order to determine their load-strain-time and temperature behaviour. Their surface friction properties may be obtained by shear box testing.

The tensile ribs formed by drawing punched sheets of polymer, either uniaxially or biaxially, have gradually varying cross-sections and properties but their overall load-strain-time and temperature behaviour can be determined using various test methodologies if special clamping techniques are employed as suggested by GRI (1987). Their surface friction properties may be obtained in a similar manner to the other types of tensile ribs using shear box testing.

Thus tensile ribs of all kinds may be appropriately characterised using existing test methodologies. The properties so determined are appropriate for quality control, (Index), purposes.

3 THE BEHAVIOUR OF JUNCTIONS

All types of junctions provide geometrical stability during transport and installation. The cross-sections of various junction types are shown in Fig. 1.

Geogrids formed with entangled or heat-bonded junctions generally have inadequate junction strength to transfer bearing stresses from cross-members or transverse tensile ribs into the tensile ribs in the direction of stressing under uniaxial stress conditions.

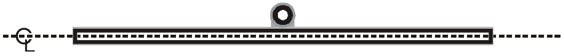
Geogrids formed with welded or integral junctions most often exhibit sufficient junction strength to transfer bearing stresses from cross-members or transverse tensile ribs into the tensile ribs in the direction of stressing under uniaxial stress conditions and to develop dynamic interlock under uniaxial or biaxial stress conditions.

The soil-interaction mechanism for grids with entangled and heat bonded junctions is dependent solely upon surface friction. However, the soil-interaction mechanisms for grids with welded and integral junctions are a combination of surface friction and bearing stresses on cross-members. Therefore for geogrids with entangled or heat-bonded junctions, the junctions need only be sufficiently strong to maintain geometrical stability during transport and installation. In contrast, for geogrids with welded or integral junctions, the junctions need much higher strength properties. This requirement was recognised some two decades ago and a test methodology was established by GRI (1987) but at a time when only integral junction geogrids were widely employed. Unfortunately this test methodology is not entirely appropriate to all the type of junctions employed in geogrid manufacture at the present time.

Discussion of the GRI-GG2 (1987) test methodology is given in a later section and a new test method appropriate to all the current junction types is detailed. However, it must be made clear that these test methods provide quality control (Index) test data and not design (Performance) test data, Murray & McGown (1982 & 1992). Design (Performance) test data can only be obtained by testing geogrid products, as well be discussed in the next section.

a) Entangled

b) Heat-bonded



c) Welded

d) Integral

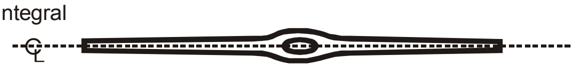


Fig. 1 Cross-sections if different junction types

4 THE OVERALL BEHAVIOUR OF GEOGRIDS

The properties of the tensile ribs and junctions contribute to the behaviour of geogrids in a complex manner, influencing both their load-strain-time and soil-geogrid interaction properties.

4.1 *Geogrids with Entangled or Heat-Bonded Junctions*

For geogrids with entangled or heat bonded junctions their load-strain-time behaviour is very closely associated with the fibres, filaments or strips used to form the tensile ribs. Thus the uniaxial properties in each orthogonal direction may be identified from the properties of the tensile ribs in those directions. Their biaxial behaviour may be simply taken to be the summation of the two uniaxial load-strain-time behaviours.

The soil-geogrid interaction properties of geogrids with entangled junctions are again very closely associated with the properties of the fibres, filaments or strips used to form the tensile ribs. Thus their soil-geogrid interaction properties may be simply calculated as the summation of the surface friction properties of the tensile ribs in the direction of stressing or measured by direct pull-out tests on tensile ribs in the direction of stressing.

Thus both the quality control (Index) and design (Performance) properties of geogrids with entangled or heat-bonded junctions can be determined directly from the quality control and performance properties of the tensile ribs using existing test methodologies.

4.2 *Geogrids with Welded or Integral Junctions*

For geogrids with welded or integral junctions their load-strain-time behaviour is markedly different from either the tensile ribs alone or the junctions alone. Indeed the contribution of the properties of the tensile ribs and junctions may vary significantly at different times of loading and under different loading regimes. Therefore for geogrids with welded or integral junctions it is necessary to test representative sized samples of the geogrid product and subject than to appropriate loading regimes over suitable time periods, in order to determine either quality control (Index) or design (Performance) load-strain-time parameters.

Similarly the soil-geogrid interaction properties of geogrids with welded or integral junctions may be determined only by testing representative sized samples of the geogrid product. In this case only, pull-out testing will provide appropriate design (Performance) data. Quality control (Index) tests are not usually appropriate or required providing that the tensile ribs and junctions have been subject to quality control (Index) testing.

Thus both the required quality control (Index) and design (Performance) properties of geogrids with welded or integral junctions can be determined only by directly testing representative sized samples of the geogrid products. Suitable test methodologies exist for all of this testing.

5 JUNCTION TESTING

From the above, it is clear that the only testing methodology that is problematic with regard to the characterisation of geogrids is junction strength testing for quality control purposes.

5.1 *Available Test Methods*

The only recognised quality control (Index) test methodologies for junction strength are reported by GRI-GG2 (1987), Montanelli & Rimoldi (1994) and the Tex-621-J (2002). These were developed for geogrids with integral junctions. For such geogrids the axis of the junctions is essentially in the same plane as the central axis of the tensile ribs. Applying an in-plane uniaxial or a biaxial loading regime to the tensile ribs does not cause any torque (rotational or tearing) force on the junction as shown in Fig. 2.

For geogrids with heat-bonded or welded junctions, the junction is offset from the central axis of the tensile ribs, Fig. 3. Thus for uniaxial or biaxial loading of such junctions a degree of torque force is applied. As a result there is often rotation of the joint and tearing of one tensile rib away from the other as shown in Fig. 3. Generally, rotation and tearing of heat-bonded or welded junctions does not occur in-soil due to confining stresses induced by the soil. Thus the GRI-GG2 (1987) and Tex-621-J (2002) test methodologies are not appropriate to these types of geogrid.

Fig. 2 Integral junctions (Junctions are in the same plane as tensile ribs)

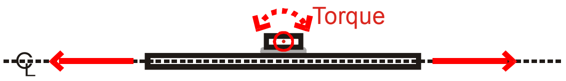


Fig. 3 Other junctions (Junctions are not in the same plane as tensile ribs)

Dependent on the methodology associated with the production of the junctions in geogrids with entangled junctions, the junctions may or may not be subject to torque forces (rotation and tearing) during GRI-GG2 (1987) and Tex-621-J (2002) testing.

Thus it is suggested that a new test method must be developed which is suitable for the identification of the quality control (Index) properties of the junctions in all types of geogrids.

5.2 *Development of the Unconfined Junction Shear Strength Test*

This testing protocol developed is directed towards obtaining the Unconfined Junction Shear Strength and it must be appreciated that the confined in-soil behaviour is likely to superior. Hence, the Unconfined Junction Shear Strengths determined in this manner is likely to be the lowest value achievable.

The Unconfined Junction Shear Strength test developed is a modification of the test method described by GRI (1987). The GRI test specimen preparation and testing conditions were modified as described below to take account of the nature and behaviour of welded junction products.

The test specimens were cut and prepared according to BS EN 20139 (1992) and exposed to the test environment of 20ºC and 60% relative humidity at least 24 hours prior to testing. The tensile test machine employed for the testing was capable of reaching loads up to 20kN applied at a constant rate of deformation. A calibrated load cell was attached to an electronic data logger. The load cell was calibrated up to the maximum load expected to be reached during testing, which was 1.5kN.

The bottom clamp used was an unmodified high friction clamp that holds the sample across its full width in the standard manner. The top clamp was modified so that the clamp firmly compressed the cross-member of the grid away from the junction on a highly frictional surface. The junction area was unconfined but constrained to ensure that it was unable to rotate within the clamp. This was achieved by providing a milled grove with identical dimensions to the flat bar. Due to the variation in grid geometry and bar dimensions of the welded geogrid product range, different clamps were used for each product type. GRI-GG2 (1987) recommends a T-shaped specimen to be used for testing. However, for the Unconfined Junction Shear Strength tests all specimen dimensions were selected in such a way that they had the same test specimen lengths as those used in for Index and Performance testing to allow direct comparisons to be made.

It should be noted that the reporting of deformations and elongations/strains in the Unconfined Junction Shear Strength test is problematic for two reasons:

Firstly, the stresses applied at the junctions are shear stresses and so the strains at the junctions are shear strains. Thus, in a similar manner to shear box testing in geotechnical engineering, it should be shear deformations [change in length] that are reported.

Secondly, given that the overall length of the test specimens will influence the deformations developed in the test specimens, the original length of test specimens should be kept to a minimum in order to identify the shear deformations at the junctions as accurately as possible, otherwise, the deformations observed during the test will be those at the junction together with those over the length of flat bar under loading.

5.3 *Materials Tested*

Biaxial geogrids made from pre-stretched and molecularly aligned monolithic flat bars which were welded together at right angles were used for the Unconfined Junction Shear Strength. The nominal product tensile strength as specified by the manufacturer for either Machine Direction [MD] or Cross-Machine Direction [XMD] ranged between 30 and 40kN/m. The polymer resin was either transparent Polyester [PET] or white Polypropylene [PP]. The product properties are summarised in Table 1.

5.4 *Test Specimens*

To test a prepared specimen it was inserted into clamps, Fig. 4, the clamps were then closed and secured, and placed into the tensile testing machine. The tests were conducted at a cross head speed of 50mm/minute, which corresponds, at an overall specimen size of approximately 125mm, to an overall strain rate of 40%/min; (although calculation of such a strain rate is not strictly applicable as discussed in a previous section). After testing, the specimen was removed from the clamps and examined to determine the mode of failure, Fig. 5.

Specimens were cut and conditioned prior to testing in the standard manner. GRI (1987) suggested the testing of at least 10 specimens to determine specimen variation. For the Unconfined Junction Shear Strength tests the number of specimens was increased to 20 samples to account for any specimen variation and to check various welding positions. All tests were conducted under identical conditions.

5.5 *Test Data Analysis*

The raw test data obtained from testing was collected by using an advanced data logger running LabView®, then analysed in Microsoft Excel® and the results are presented with the Origin® graph plotting software.

5.6 *Test Results*

Test results from the Unconfined Junction Shear Strength tests are summarized in Table 2 and shown in Figs. 6 to 9.

Table 1 Material properties of geogrids tested

Technical Data	Unit	Biaxial Geogrid			
		A	B	C	D
Resin	[-]	PP	PP	PET	PET
Nominal Tensile Strength [MD/XMD]	[kN/m]	≥30	≥40	≥30	≥40
Strain at Nominal Strength [MD/XMD]	[%]	≤8	≤8	≤8	≤8
Tensile Strength at 2% strain [MD/XMD]	[%]	12	16	13.5	18
Grid dimensions	[mm]	32×32	32×32	34×34	33×33

Table 2 Summary of test results

Data	Unit	Biaxial Geogrid			
		A	B	C	D
Unconfined Junction Shear Strength	[N]	652	660	1274	1212
	[kN/m]	16.9	17.1	33.1	31.5
Standard Deviation	[kN/m]	0.75	0.65	0.68	0.81
Unconfined Junction Shear Strength vs. Uniaxial Strength at 2% Operational Strain	[-]	>100%	>100%	>100%	>100%

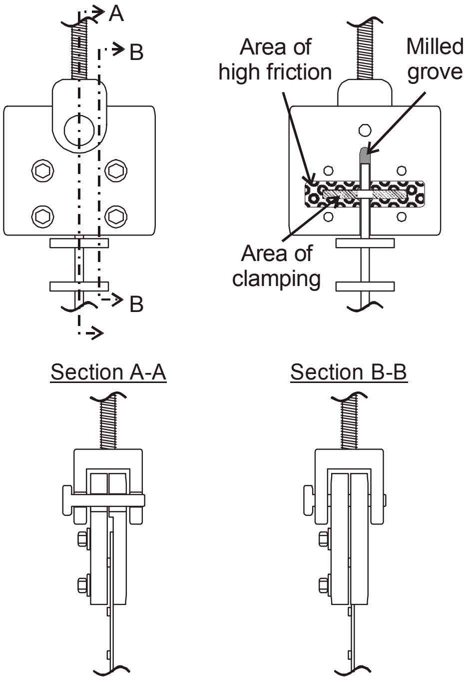
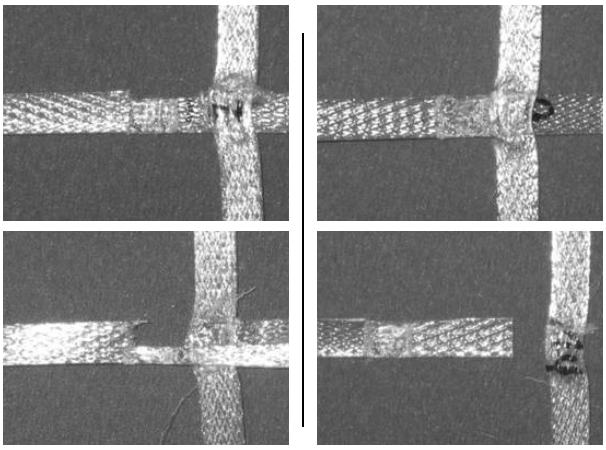


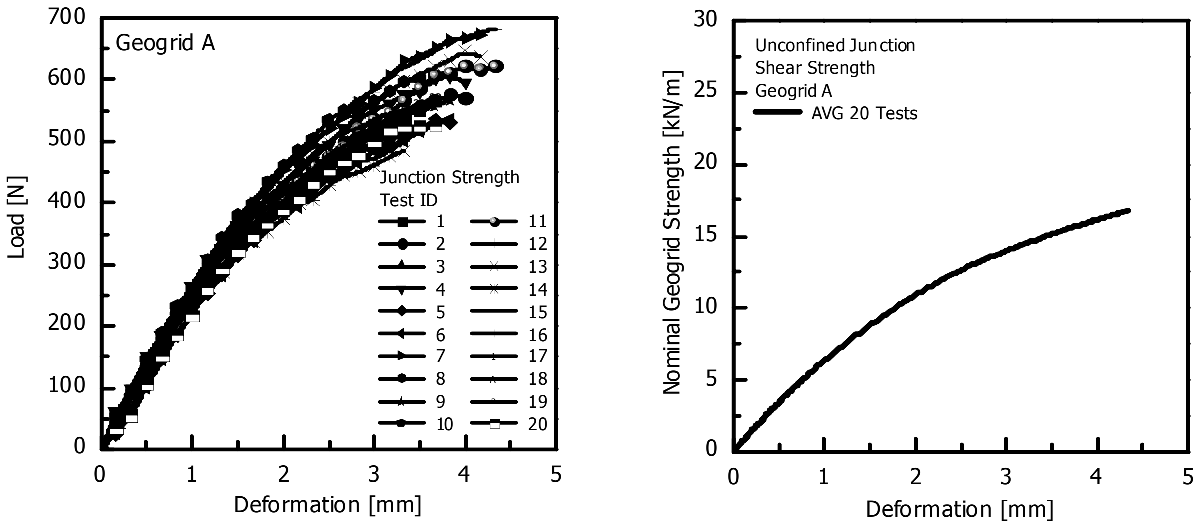
Fig. 4 Top clamp developed for the Unconfined Junction Shear Strength tests



(a) Junction Rupture

(b) Shear displacement and separation

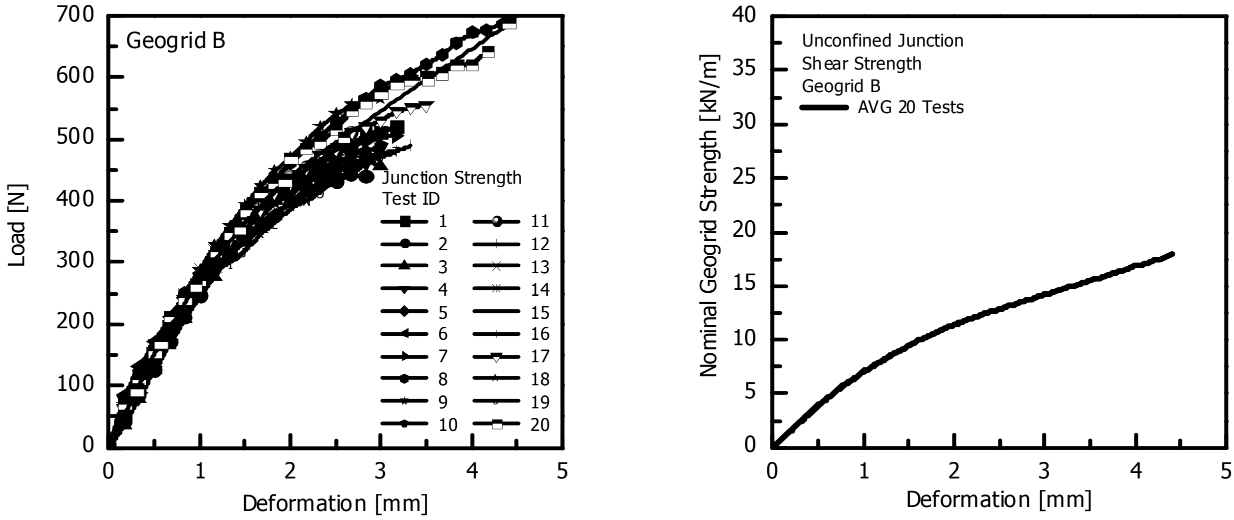
Fig. 5 Mode of failures



(a) Strength of individual junctions [N]

(b) AVG test data [kN/m]

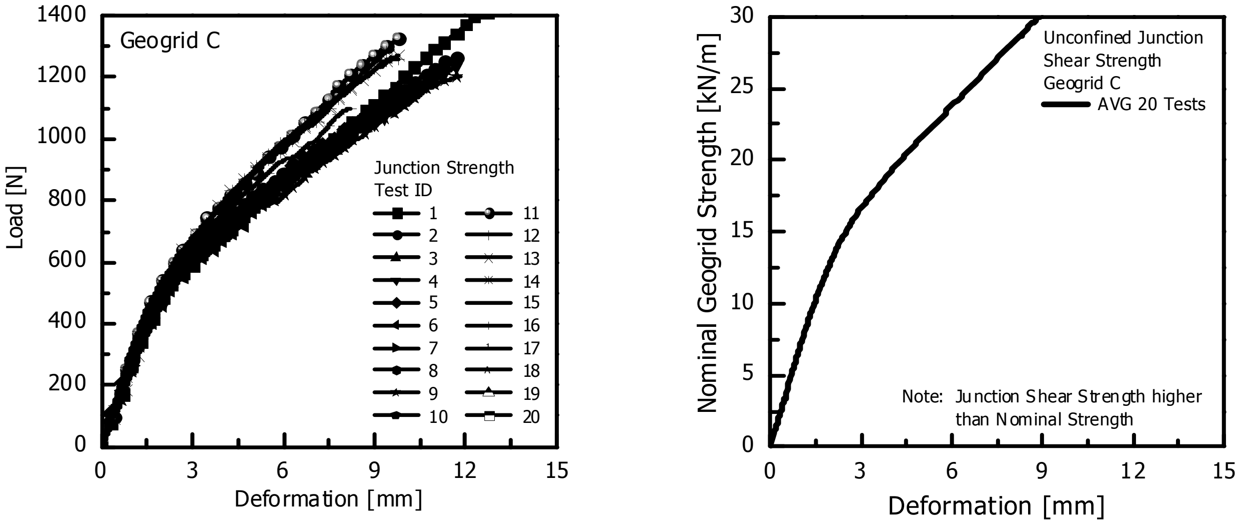
Fig. 6 Unconfined Junction Shear Strength test results - Geogrid A



(a) Strength of individual junctions [N]

(b) AVG test data [kN/m]

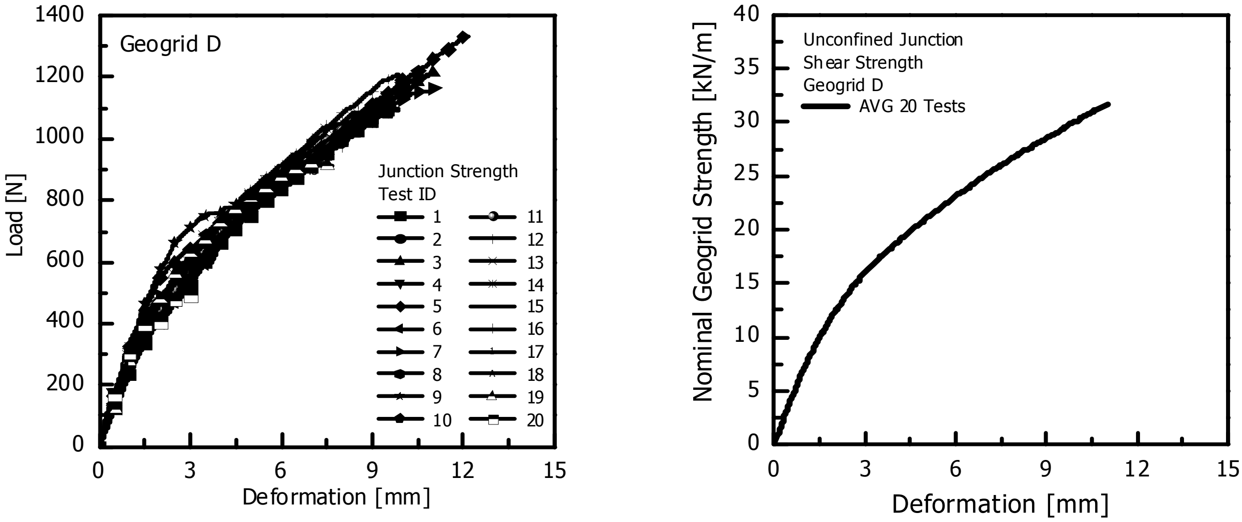
Fig. 7 Unconfined Junction Shear Strength test results - Geogrid B



(a) Strength of individual junctions [N]

(b) AVG test data [kN/m]

Fig. 8 Unconfined Junction Shear Strength test results - Geogrid C



(a) Strength of individual junctions [N]

(b) AVG test data [kN/m]

Fig. 9 Unconfined Junction Shear Strength test results - Geogrid D

6 INTERPRETATION OF THE UNCONFINED JUNCTION SHEAR STRENGTH TEST DATA

The interpretation of test data is based on the assumption that normal operational conditions are maintained during the structural design lifetime. Strains developed under normal operational conditions are reported to be much lower than currently assumed in design, Bell (1977), Berg et al (1986), Simac et al (1990), Yogarajah (1992), Stolarski & Gartung (2001), Rowe & Li (2001), Murate et al (2001) and Zornberg & Arriaga (2003). These researchers report strain levels of less than 1% after more than a decade of continuous service. Hence to relate the developed product strain for most applications with respect to Serviceability [SLS] at the end of design lifetime a limiting strain of 2% is suggested. Thus the test data obtained from Unconfined Junction Shear Strength testing were compared to data obtained under CRS test conditions at limiting strain levels of 2%. To enable comparisons to be made to CRS test results the individual junction shear strength was multiplied by the number of junctions per metre grid and hence a maximum Unconfined Junction Shear Strength per cross member was calculated, Table 2. Additionally, Table 2 shows a very low Standard Deviation from the test data which indicates very uniform and consistent welding processes are used.

Furthermore, it is shown that the Unconfined Junction Shear Strength is much higher than the tensile strength developed under working conditions.

As stated previously, more than one cross-member is operational in practice and the junctions are confined, hence the operational significance of this interpretation is not considered to be important. The practical significance of these test data should be limited to quality control (Index) purposes only, i.e. for the assessment of the uniformity of the welds.

7 CONCLUSIONS

(i) Geogrid junctions are produced in a variety of manufacturing processes and may have multiple functions.
(ii) Junction shear strength has been identified as an important material property.
(iii) It is important to understand the operational behaviour of Geosynthetic Reinforced Soil Structures, i.e. the development of either in-plane uniaxial or in-plane biaxial loading conditions, the confining pressures on the grid and junction, the stress and strain distribution along the grid, etc.
(iv) Strains associated with most applications, subject to normal operational conditions are of the order of 1or 2 per cent tensile strain at the Serviceability Limit State.
(v) Stresses are very likely to be distributed along the anchorage length with more than one cross member involved. It is therefore not an operational requirement that only one cross-member is required to enable full load transfer from the soil to the geogrid. Indeed, multiple cross-members may be involved in order to provide satisfactory Anchorage.
(vi) With the levels of loads generated per cross-member found in this test series, the Junction Shear Strength of the welded geogrids tested appears to be more than adequate.
(vii) Unconfined Junction Shear Strengths are the lowest values achievable. Thus, the confined in-soil behaviour is likely to be superior.
(viii) Further research is required to fully appreciate the anchorage behaviour of welded geogrids under operational conditions, as it will be different to the behaviour of geogrids with entangled, heat bonded or integral junctions.

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