Characterising the short term low-strain radial tensile behaviour of a multi-axial geogrid.

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ABSTRACT: It is recognised that the critical properties of multi-axial geogrids, when used for the stabilisation of unbound granular materials, are their interlock capability and short-term, in-plane, low-strain, tensile stiffness in all radial directions. Their interlock characteristics are well understood, but not their short-term, low-strain radial tensile stiffness. To date wide-width, uniaxial CRS tensile tests carried out in multiple directions have been used to determine this property, but the validity of this approach has not been investigated. Therefore a new, in-plane, radial tensile test apparatus and test methodology has been developed for this purpose. Test data obtained from this new radial tensile test has been compared to that obtained from multi-directional uniaxial tensile testing and found to be closely correlated. Thus the multi-directional, uniaxial constant rate strain (CRS) tensile test is shown to be a reasonable and conservative means of determining the short-term, low-strain, radial tensile stiffness of multi-axial geogrids and the need for more elaborate testing methodologies is not required.

Keywords: geogrid, low strain stiffness, uniaxial, radial secant stiffness, test methods

1 INTRODUCTION

Multi-axial geogrids are now used in civil engineering applications and appropriate means of testing them are required for quality control, specification and performance related purposes. The recently introduced TriAx® geogrids are one type of these multi-axial geogrids. They are geogrids with integral junctions and ribs in three directions arranged to form hexagonal structural units with equilateral triangular apertures, Fig.1. They are intended to provide a stabilisation function in road pavements and other associated applications and the mechanism involved is the restriction of lateral movements in unbound granular layers subject to trafficking. This is achieved by the use of a stiff geogrid with integral junctions and apertures of appropriate size and shape, interlocking with the soil or aggregate forming the unbound granular layer.

Giroud (2009) and Giroud and Han (2016) suggest that the main benefit of multi-axial geogrids would be to efficiently interlock with the sub-base materials to prevent, or at least minimise, lateral spreading, (deformation), of the sub-base. They suggest that consideration should be given to the development of radial deformations, rather than uniaxial or biaxial deformations, as has been the case previously, Fig.2. Further, it is suggested that the function of these geogrids is to restrict outward radial deformations at low-strains rather than large strains and given that transient traffic loading is inducing these strains, it is their short-term, low-strain, radial, tensile stiffness combined with their interlock characteristics, that is important.

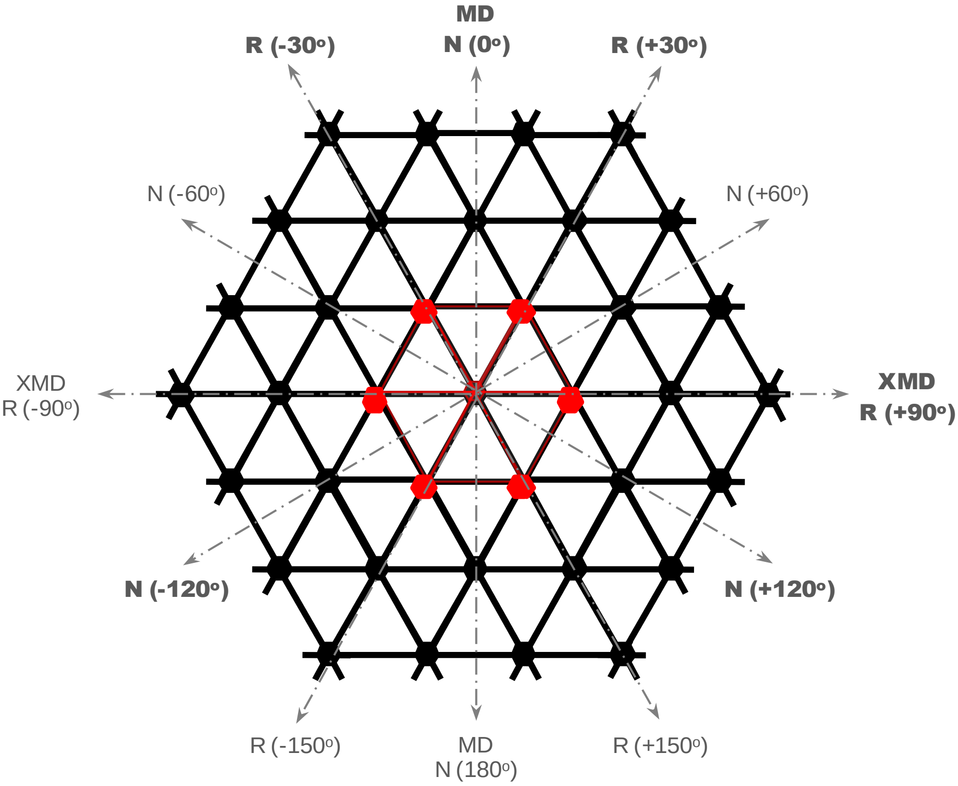


Fig.1: The basic hexagonal structural unit showing the mid-rib and rib directions.

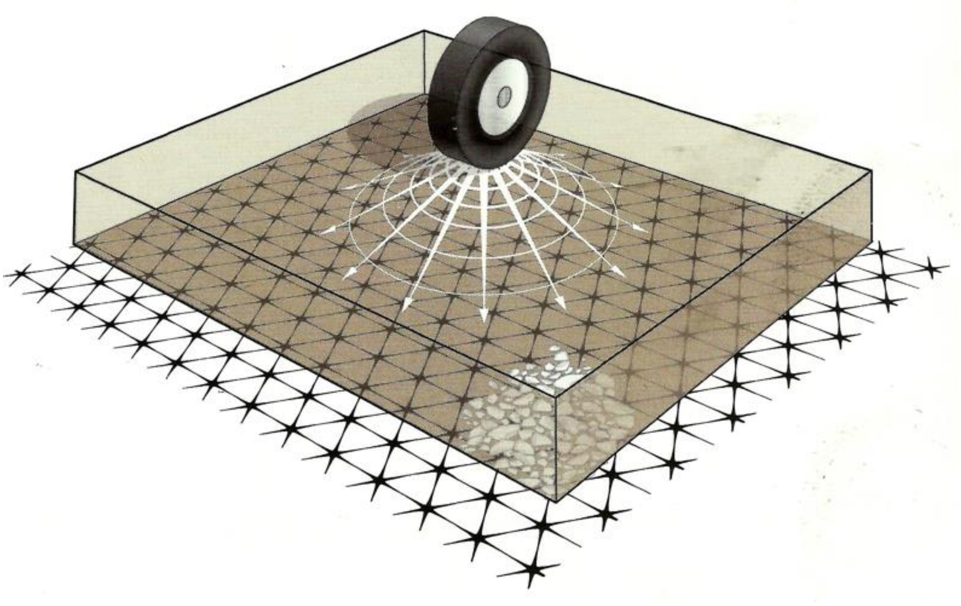


Fig.2: The tyre loading the pavement and radial distribution down into the sub-base/ sub-grade.

The interlock characteristics of stiff geogrids with integral junctions have been widely investigated, e.g. Jewell et al (1984), Konietzky et al (2004) and Tutumluer and Al Qadi (2009), however the short-term, low-strain, radial tensile load-strain behaviour of geogrids is less well established.

For the purposes of awarding European Technical Approval to the TriAx® geogrids for use as a stabilisation geogrid, EOTA (2012), adopted the methodology of uniaxial CRS, wide-width tensile testing of the geogrids in four directions, based on the test methodology of EN ISO 10319 (2008). Further, they identified the radial secant stiffnesses at 0.5 per cent strain to be an essential characteristic. To determine the variation of the radial secant stiffness in these four directions, ("Stiffness Isotropy"), they calculated the "Radial Secant Stiffness Ratio", defined as the minimum to the maximum secant stiffness at 0.5 per cent strain, measured in the four directions.

To establish if the approach taken by EOTA (2012) reasonably characterises the short-term, low-strain, radial, tensile stiffness of these geogrids, an extensive research programme was undertaken. The objective of the research was to develop an appropriate and practical in-plane radial tensile test methodology and to compare the data obtained from this to the data obtained following the EOTA (2012) test methodology. Uniaxial CRS and radial sustained load (Creep) testing was undertaken to allow assessment of these test methodologies. Test specimens were all taken from a single production batch of TriAx® TX 160 in order to limit possible variations in the test data from production and other causes not linked to the test methodologies.

In this paper, the current approaches to the Q.C., Index and Performance Related testing of geogrids are described. Next the details of the in-plane, radial test method are set out. Uniaxial CRS and radial Creep test data are then presented and a comparison made of the test data obtained. The outcome of this comparison is discussed and conclusions drawn on the validity of the uniaxial testing approach adopted by EOTA (2012).

2 CURRENT APPROACHES TO TENSILE TESTING OF GEOGRIDS

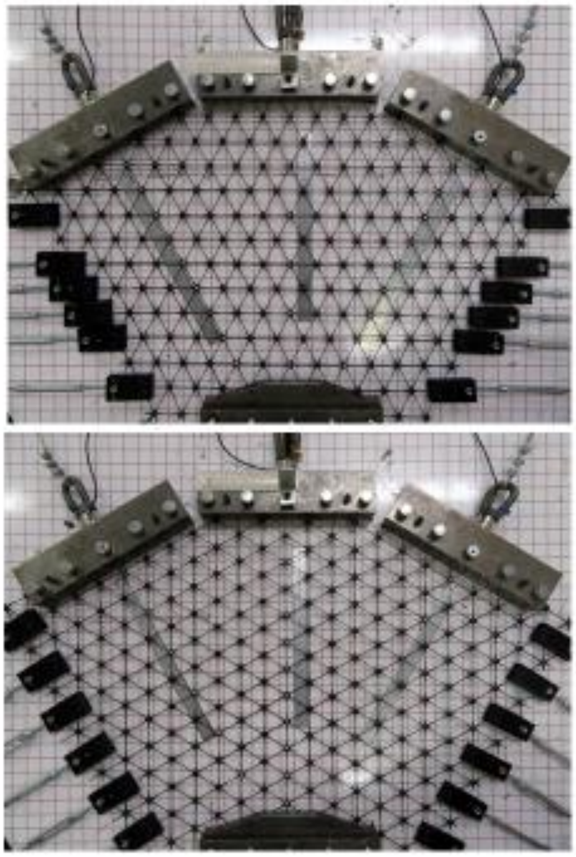
In-plane, wide width, uniaxial CRS tensile test methods for determining the Q.C. and Index properties of uniaxial and biaxial geogrids with integral junctions, were first developed by McGown et al (1984). These test methods have now been adopted in modified form as international standards, e.g. EN ISO 16319. The uniaxial geogrids are tested in their principal direction of strength and biaxial geogrids are tested in the machine and cross-machine directions, which are their principal directions of strength. Attempts to combine the directional properties of biaxial geogrids obtained in this manner, has proven to be problematic. Further, it was reported that conventional uniaxial tensile testing could not be used to reasonably predict material stiffness as the biaxial values were likely to be several times higher, Nimmersgern (1994). Therefore, Kupec (2004) developed an in-plane biaxial test apparatus and undertook biaxial CRS and Creep testing. However, these biaxial test methodologies have not been further developed as the data from uniaxial test methods was proven to provide reasonable and conservative values.

Walsh (2006) recognised that in order to assess TriAx® geogrids, it was necessary to undertake testing in four directions, viz. in the two 'mid-rib' directions (0° and 60° - with respect to the machine direction) and the two 'rib' directions (30° and 90° - with respect to the machine direction). EOTA (2012) adopted the same approach of uniaxial CRS, wide-width tensile testing of the geogrids in the four directions and based the test methodology on EN ISO

10319. As with biaxial geogrids, the question arises as to the validity of adopting uniaxial test methods to characterise the properties of multi-axial geogrids. Thus it was decided to develop an in-plane, radial test method for the multi-axial geogrids and to compare the test data from radial tests to the test data from the uniaxial tests.

3 THE IN-PLANE RADIAL TENSILE TEST METHODOLOGY

The new in-plane radial tensile test method involves testing 90^0 segments of the multi-axial geogrid held with a fixed 300mm wide inner clamp and three 300mm wide outer clamps moving outwards under equal applied loads. A series of edge restraints are used to maintain the lateral dimensions of the test specimen. A series of tests is carried out with the two "mid-rib" and in the two "rib" directions variously oriented to the central axis of the test. The overall test set-up in the various directions are as shown in Figs. 3 and 4.



a) "Mid-rib" direction test specimen

b) "Rib" direction test specimen

Fig.3: The two test specimen shapes.

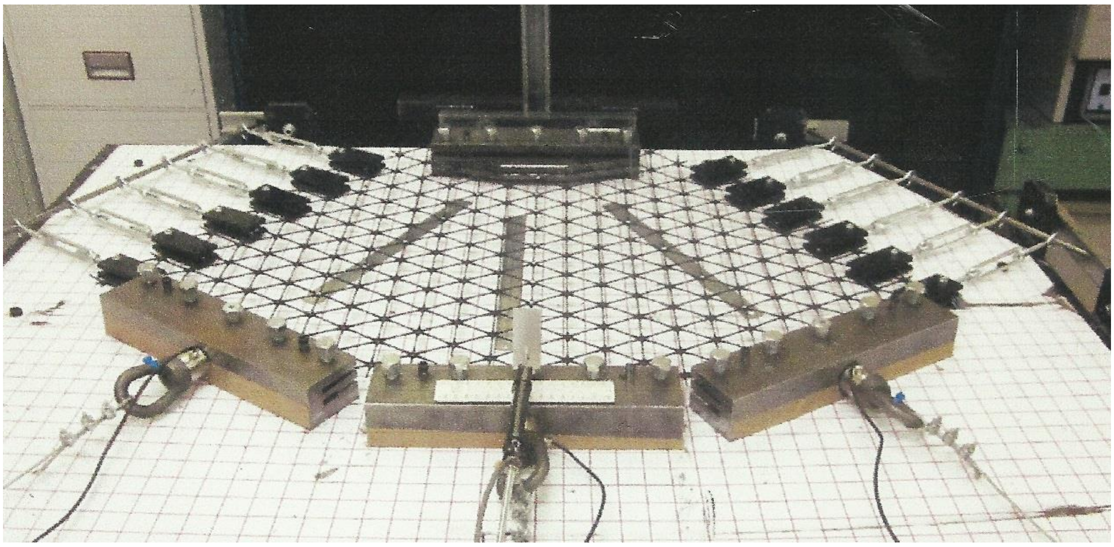


Fig. 4: The radial test set-up

The applied loads in the three radial outward directions are measured using load cells and the central outward radial deformations are measured by a LVDT attached to the central outer clamp. Digital photography is employed to establish that the test specimens are acting in a radial manner and that the induced radial strains are consistent with the variation of applied loading along the radial directions.

Creep tests were conducted and the applied loads and overall central radial deformations were recorded and photographs taken of the initial set-up conditions and at regular intervals during the tests. A range of sustained loads was applied in the Creep tests for periods up to 10 hours. The average radial loads per metre width and average radial strains along the central radial direction of the test specimens were calculated and using these data, the isochronous radial secant stiffnesses at 0.5 per cent strain of the geogrid were determined.

4 IN-PLANE UNIAXIAL CRS TEST DATA

The in-plane, wide-width tensile CRS tests were generally conducted in accordance with EN ISO 10319, but were undertaken at strain rates of 0.02, 0.2, 2.0 and 20 per cent minute. Five CRS tests were tested in each of the four test specimen orientations. Using the test data so obtained, the isochronous secant stiffnesses at 0.5 per cent strain were calculated and plotted as shown in Figs. 5 and 6.

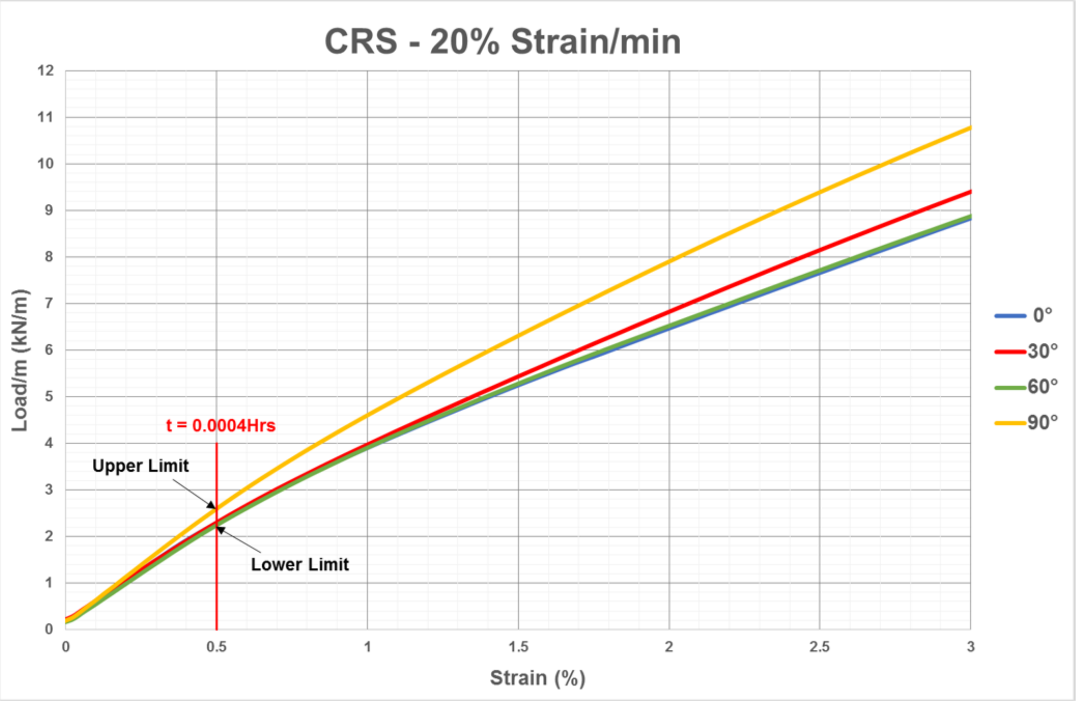


Fig. 5: Typical uniaxial CRS test data.

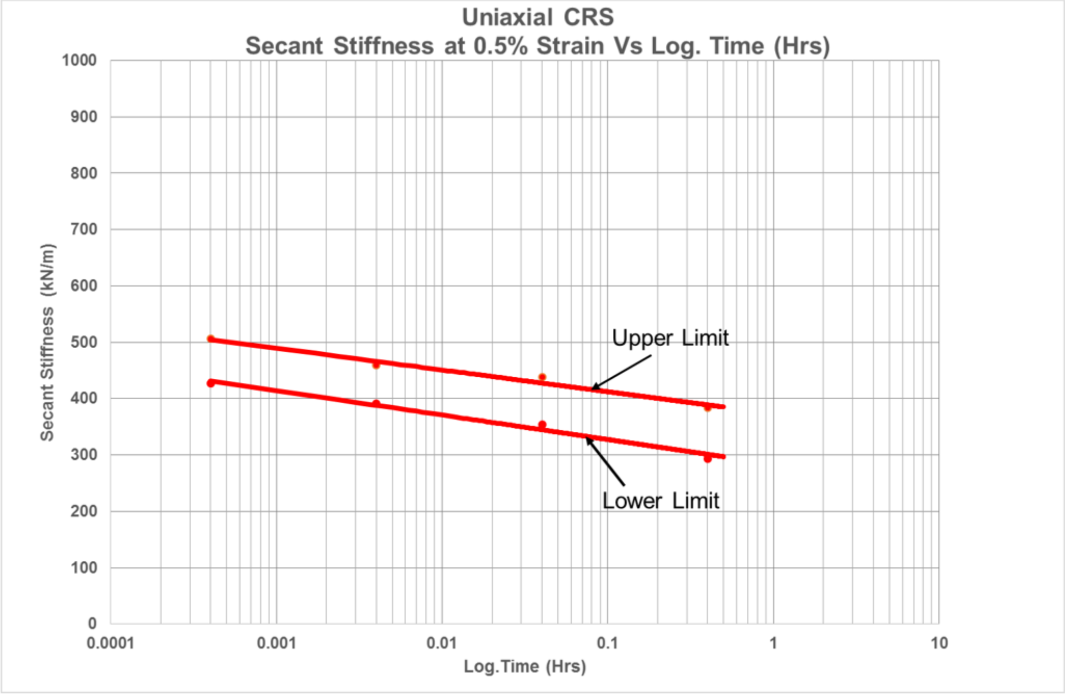


Fig. 6: Uniaxial isochronous secant stiffness at 0.5% strain vs log. time.

5 IN-PLANE RADIAL CREEP TEST DATA

The in-plane, tensile, 90^0 segment, Creep tests were conducted with the central radial direction in four orientations with respect to the structure of a multi-axial geogrid and three equal sustained loads on each of the three outer clamps. These loads were 30, 40 and 50 kg. Using the test data so obtained the isochronous radial secant stiffnesses at 0.5 per cent strain, were calculated in the manner shown in Figs. 7 to 9.

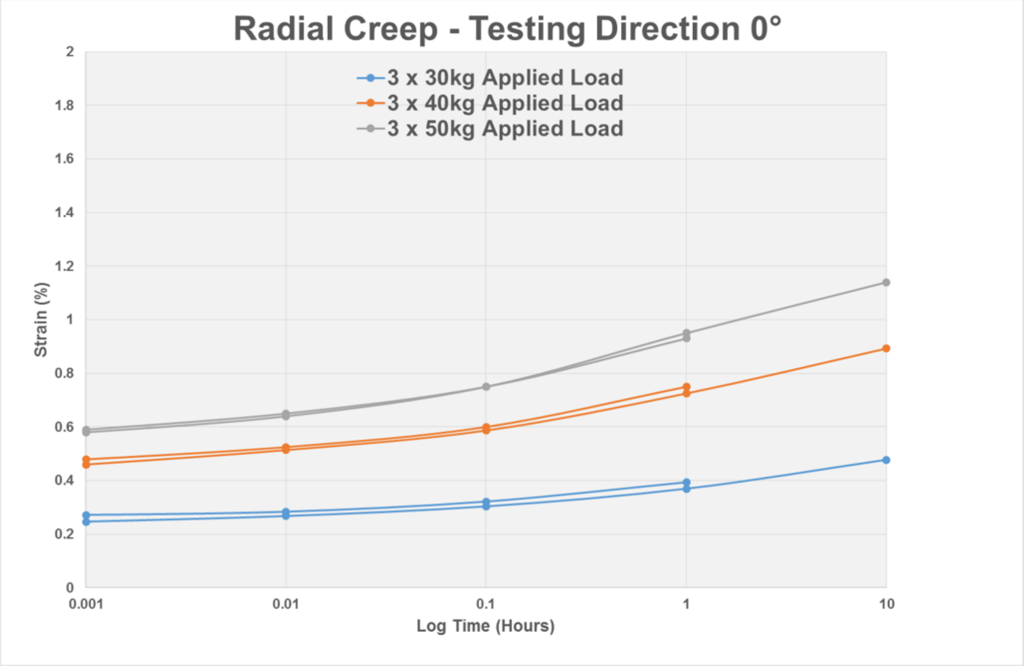


Fig 7: Typical radial creep test data

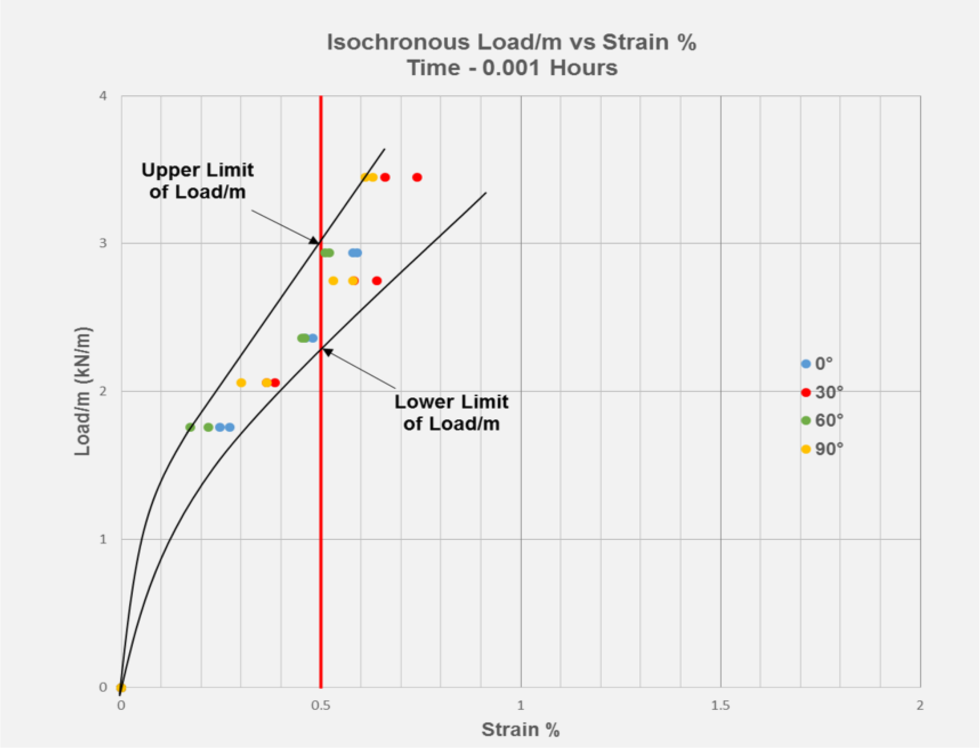


Fig 8: Typical isochronous load/m vs strain plot.

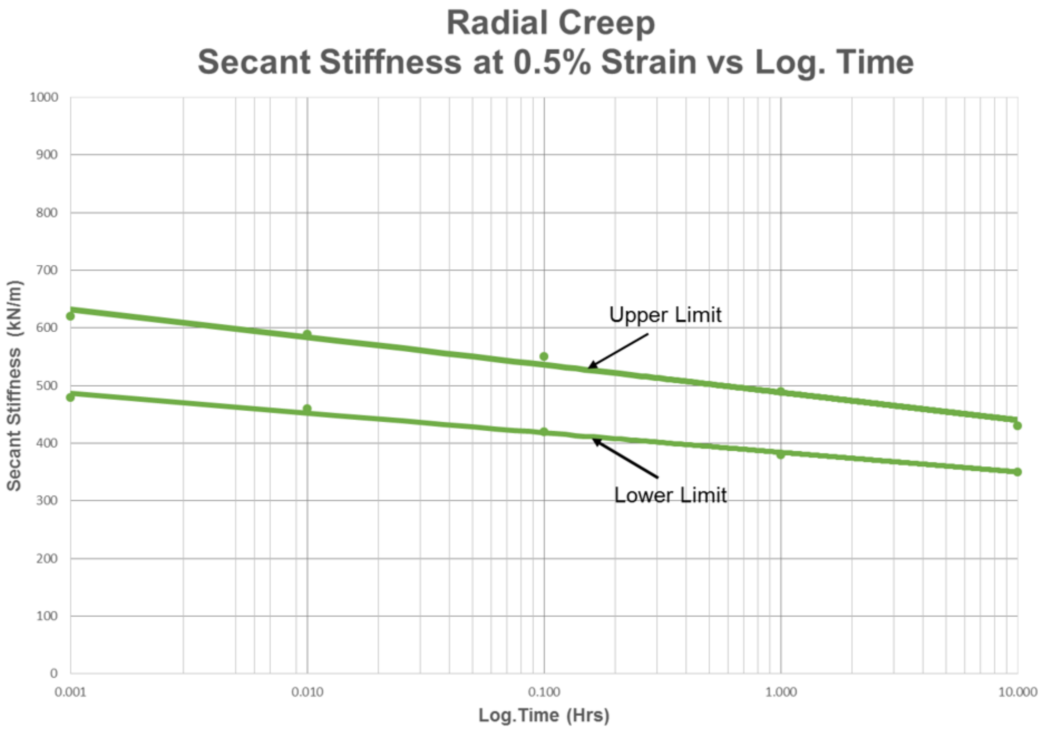


Fig 9: Radial isochronous secant stiffness at 0.5% strain vs log time.

6 COMPARISON OF THE UNIAXIAL AND RADIAL TENSILE TEST DATA

The upper and lower limits of the isochronous uniaxial and radial secant stiffnesses at 0.5 per cent strain were determined and plotted against log time in hours and are shown in Fig. 10. This plot demonstrates that there is a consistent and reasonable correlation between the test data obtained from the wide width, uniaxial CRS tensile tests and the 90^0 segment, radial tensile Creep tests.

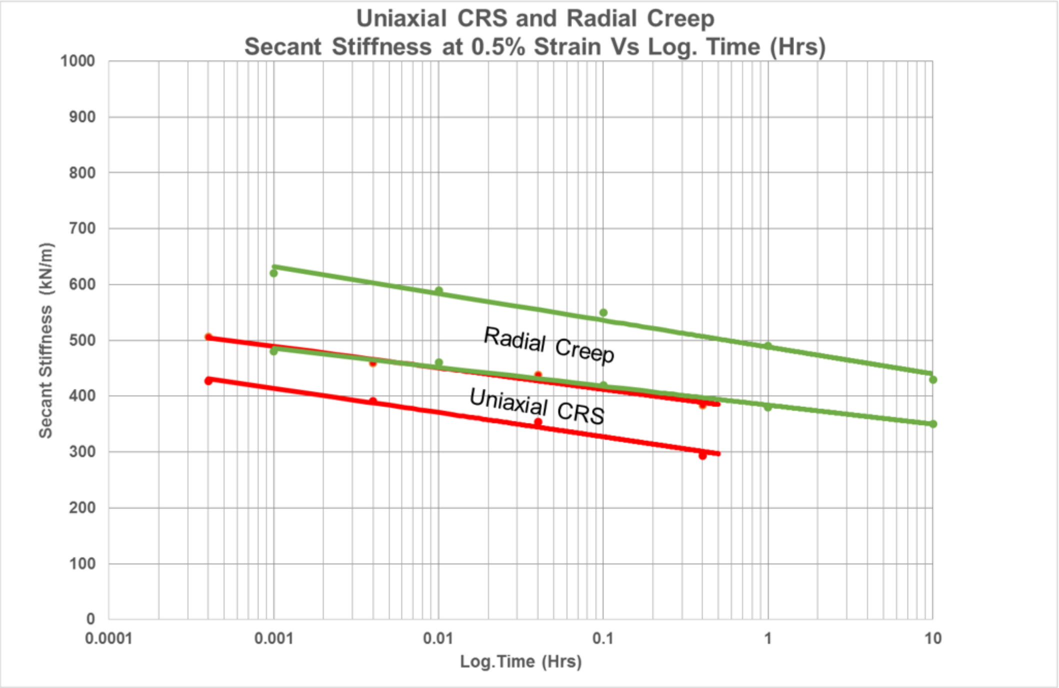


Fig 10: Comparison of the uniaxial and radial isochronous secant stiffnesses at 0.5% strain vs log time.

7 DISCUSSION AND CONCLUSIONS

The critical properties of multi-axial geogrids in the stabilisation of unbound pavements have been identified by Giroud (2009) and Giroud and Han (2016) as their short-term, low-strain, radial tensile stiffness and their interlock characteristics. The interlock characteristics of stiff geogrids have been widely investigated and are well understood, but this is not the case for their short-term, low-strain, radial tensile stiffness.

For the purposes of awarding European Technical Approval for multi-axial geogrids in subgrade stabilisation, EOTA (2012) adopted the methodology of in-plane, wide-width uniaxial testing in multiple directions in order to determine the short-term, low-strain radial tensile stiffness of the geogrids, however, the validity of this testing approach required to be confirmed. Therefore, a new in-plane, radial, tensile radial test method was developed employing 90^0 segment shaped test specimens.

Both uniaxial CRS and radial Creep testing was undertaken on a single batch of TriAx® TX160 geogrid and the in-plane, radial secant stiffnesses at 0.5 per cent strains over relatively short time periods of up to 10 hours were obtained. It was found that there was a close correlation between these data. Thus the multi-directional, uniaxial CRS tensile test was shown to be a reasonable and conservative means of determining the short-term, low-strain, radial tensile stiffness of multi-axial geogrids and the need for more elaborate testing methodologies is not required.

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