UNCONFINED IN-PLANE JUNCTION SHEAR STRENGTH TESTING

for

Secugrid® 30/30 Q1

J Kupec & A McGown
University of Strathclyde – Glasgow – UK
July 2003

-ENGLISH-

Department of Civil Engineering
John Anderson Building
107 Rottenrow
G4 0NG Glasgow
United Kingdom

T: +44-141-548-4751
F: +44-141-553-2066
E: jan.kupec@strath.ac.uk
geotech@strath.ac.uk

1. Preamble

This report is a brief summary of Unconfined Junction Shear Strength testing for Naue Fasertechnik GmbH & Co KG. The aim of this work was the modification of the GRI (1987) GG2 Junction Strength test method to make it suitable for geogrids with welded junctions. To achieve this, a considerable amount of product and junction strength testing has been carried out on a variety of Secugrid® products and a re-appraisal of the mechanisms involved in load transfer within grids with welded junctions under different operational conditions has been made.

2. Introduction – Junction Efficiency

Junctions, sometimes referred to as nodes, are the intersections of geogrid members (ribs). The nature of these intersections are highly dependent on the manufacturing process employed and hence will vary for different product types, Thus geogrids may have entangled, welded or bonded junctions or have junctions formed through drawing, i.e. integral junctions. Secugrid® products, e.g. Secugrid® 30/30 Q1, are formed with welded junctions.

No test protocols, national or international standards for junction strength testing of geogrids with welded junctions exist. A few procedures, i.e. GRI GG2 and Tex-621-J have been developed for drawn junctions but these are not totally suitable for welded junctions. Therefore, the aim of this report is to establish test procedures for the welded junctions in Secugrid® products that replicate their behaviour under operational conditions. It should be noted that junction strengths have to be related to product strengths at strain levels that are characteristic of the site conditions.

Included in this report are descriptions of the mechanisms involved in load transfer under different operational conditions for geogrids with welded junctions. Further, the role of different types of test methodologies are critically reviewed and the most appropriate test protocols for Unconfined Junction Shear Strength testing of geogrids with welded junctions, are set out. Test results are presented and an interpretation given of the engineering significance of these test data. Recommendations for future research are included at the end of this report.

3. The Mechanisms Involved in Load Transfer within Grids with Welded junctions under Different Operational Conditions

Secugrid® products comprise stretched monolithic flat bars in two orthogonal directions connected at cross-over points by welding.

Under uniaxial in-plane loading conditions, e.g. Constant Rate of Strain [CRS] or Sustained (creep) loading, the load in the product is generally transmitted through the set of flat bars in the direction of loading. At the junctions, it passes through the flat bars in the direction of loading and to some extent through the weld. The flat bar in the orthogonal direction contributes little to the load transfer along the product. In contrast, under biaxial in-plane loading conditions, e.g. CRS or Sustained (creep) loading, the load in the product is generally transmitted through both sets of flat bars and at the junctions it passes through both sets of flat bars and the entire area of the weld.

When used in soil as a reinforcement layer, loads in Secugrid® products are transmitted from the soil to the grid by surface friction on the longitudinal and traverse flat bars and the junctions. In addition there are lateral bearing pressures on the transverse members. The lateral bearing pressures generate shear forces at the junctions.

In some particular applications the lateral boundary conditions are such that, there is the possibility of soil being retained by Secugrid® products, e.g. when they are used as a wrap-around. In such situations, the junction could be placed under either normal compression, or normal tension depending on how it is placed. The specified use of Secugrid® products is such that it precludes the possibility of normal tension being developed therefore operationally this is not a situation that requires further consideration.

In hand held specimens it is possible to disrupt the junctions by tearing or peeling, i.e. by pulling up one set of flat bars whilst pulling down the other set of bars close to the junctions. This is not a situation that applies under operational conditions and therefore requires no further consideration.

Under operational conditions there are three mechanisms involved in load transfer within Secugrid® products, which are uniaxial and biaxial load transfer and shear force transmission. For these mechanisms, certain characteristic properties need to be determined and these are:

(i) In-plane uniaxial strength at a specific strain level,

(ii) In-plane biaxial strength at a specific strain level and

(iii) In-plane shear strength of a single junction or cross-member.

In each case, the loading in the Secugrid® products may be generated under CRS or Sustained loading conditions. The most critical situation for either loading condition will be when the confining stresses on the junction are minimal. Thus from a testing point of view, the worst case must be the testing of junctions in an unconfined condition. Hence, the data presented in this report are the unconfined values, which are the lowest values achievable. Specifically, the report describes the test methods appropriate to *Unconfined In-plane Strength Testing* and *Unconfined In-plane Shear Strength Junction Testing*. Test results are presented for Secugrid® 30/30 Q1.

4. IDENTIFICATION AND DEVELOPMENT APPROPRIATE OF TEST METHODOLOGIES

Previous researchers who have undertaken junction tests include, GRI (1987), Montalli (1994), McGown & Kupec (2001) and Texas Department of Transportation (2002), but these have been restricted to unconfined CRS tests and have exhibited various shortcomings with respect to geogrids with welded junctions, including clamp slippage and junction rotation during testing. Thus test protocols require to be developed to assess all three of the operational mechanisms to which Secugrid® products may be subjected.

Geogrids can be and have been previously formed with either entangled junctions or integral junctions. It is important to understand the differences in the load transfer mechanisms of these products compared to welded junction products in order to determine appropriate test methods and enable a meaningful interpretation of test data.

Products with entangled junctions have pre-stretched tension bars or fibres that are chemically or physically bonded together at cross-over points. Such entangled junctions do not significantly modify the bar or fibre properties nor do the junctions significantly contribute to the transfer of forces from the soil to the grid, i.e. anchorage can be assumed to be due to frictional forces on the longitudinal bars only, resulting in relatively long anchorage lengths. Thus, products with entangled junctions may be characterised by their bar strength and strains together with surface friction properties only. The characteristic product strengths and strains quoted for these geogrids are bar or fibre strengths and strains.

Products with integral junctions have semi-crystalline (highly oriented molecules) pre-stretched bars and amorph (randomly oriented molecules) unstretched to poorly stretched junctions that may be weaker and more deformable than the bars. Load transfer from the soil to the grid is due to surface friction on both the longitudinal and transverse bars and to lateral bearing stresses developed at the cross-members from soil locked into the apertures between the bars. The characteristic strengths and strains quoted for these geogrids are product strengths and strains as it is both difficult and uncommon to test the properties of bars and junctions separately.

Products with welded junctions, e.g. Secugrid® products, are formed using pre-stretched monolithic flat bars. These are welded together at right angles and the geogrid so formed can be subjected to various tests to determine its properties. Although it is simple and usual to test the bars prior to welding, product properties are usually stated, as shown in Table 1. These product strengths and strains take full account of the effects of welding on the bars and the junctions. Thus the stated product strengths and strains in Table 1, at ultimate or limiting strains, take into full account the effects of welding.

Thus, different types of geogrids may be characterised by their bar strengths or product strengths or a combination of these. Therefore, two main points need to be addressed:

(i) The importance of the In-plane Junction Load-Deformation Behaviour with respect to In-plane Load Transmission and

(ii) The importance of In-plane Junction Shear Strength with respect to Anchorage.

With respect to In-plane Load Transmission, in-plane uniaxial or biaxial loading conditions may be applied to geogrids. For entangled junctions, there is little effect from the junctions on the properties of the bars under both loading conditions. For integral junctions, the nature of the junctions greatly influences the load-strain characteristics under both uniaxial and biaxial loading conditions. For welded junctions, the nature of the junctions has some influence on the load-strain characteristics under both uniaxial and biaxial loading conditions, but less than for the integral junctions.

In-plane Junction Shear Strengths are of importance in applications where loads are transferred from the soil into the grid via lateral bearing stresses on the cross-members and short Anchorage lengths are required. To be effective in this way, junctions require to possess a resistance against shear forces generated by the cross members being pushed by the soil. Thus, In-plane Junction Shear Strengths under working conditions are important properties when Anchorage has to be considered. Pull-out tests on various geosynthetics indicated that the tensile load applied may be distributed gradually over a number of cross-members, Fahmy (1981) and Yogarajah (1993), Fig. 1. However, it has generally been found that the higher the junction shear strengths the fewer the number of junctions required and the shorter the anchorage lengths. However, rarely is a geogrid expected to exhibit full anchorage with one cross member only. Thus, the ratio of 100 per cent In-plane Junction Shear Strength to In-plane Product Strength does not apply under normal working conditions as the Anchorage length is in most cases longer than one cross member. Thus this criterion should not be regarded as an operational requirement.

4.1. Unconfined In-plane Uniaxial Load-Strain (Strength) Testing

The test protocol employed for the purposes of this report was the test procedure established for Constant Rate of Strain [CRS] testing, as described in BS 6906 (1987), modified only by test specimen sizes and the clamping conditions. The test specimens were cut and prepared according to BS EN 20139 (1992) and were 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 5kN 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.

Test data obtained from Naue Fasertechnik GmbH & Co KG for the Secugrid® product range is summarized in Table 1. Similar results were obtained at the University of Strathclyde, McGown & Kupec (2001).

A similar set of comparative test data could have been obtained for sustained loading. The test protocol used for sustained loading would be based on BS6909 (1991).

In view of the discussion in previous sections, it should be mentioned again that the product strengths and strains measured are different from those which can be obtained from testing the plain bars arranged in the same manner but not welded.

4.2. Unconfined In-plane Biaxial Load-Strain (Strength) Testing

New test protocols require to be developed for this operational mechanism. However, this topic will be the subject to a subsequent report and will not be dealt with in this report. However, it should be noted that similar comments regarding the differences between product properties and bar properties apply to this form of testing.

4.3. Unconfined In-plane Junction Shear Strength

With regard to In-plane Junction Shear Strength testing. The first stage must be to provide a clear explanation of the operational mechanism involved, as this will very much dictate the interpretation of the test data obtained. Further it must be made clear that the testing protocols employed are directed towards obtaining the Unconfined In-plane Junction Shear Strength and that the confined in-soil behaviour is likely to superior. Hence, the Unconfined In-plane Junction Shear Strengths determined in this report are likely to be the lowest values achievable.

The Unconfined In-plane Junction Shear Strength test developed is a modification of the test method described by GRI (1987). The aim of the GRI (1987) test was the determination of a maximum tensile force for an individual junction. The GRI test specimen preparation and testing conditions were therefore 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 5kN 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 is an unmodified high friction clamp that holds the sample across its full width in the standard manner. The top clamp is modified so that the clamp firmly compresses the cross member of the grid away from the junction on a highly frictional surface. The junction area is unconfined but constrained to ensure that it is unable to rotate within the clamp. This is achieved by providing a milled grove with identical dimensions to the flat bar. Due to the variation in grid geometry and monolithic bar dimensions within the Secugrid® product range, different clamps will be needed for each product type. GRI (1987) recommends a T-shaped specimen to be used for testing. However, for the Unconfined In-plane Junction Shear Strength tests all specimen dimensions were selected in such a way that they had test specimen lengths the as those used in Unconfined In-plane Uniaxial Strength tests.

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

(i) 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 [mm] that are reported.

(ii) Given that the length of the test specimens will influence the deformations developed in the test specimens, the 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. Further studies are required to determine the relationship between specimen lengths and shear deformations for Secugrid® products.

5. TEST METHODOLOGY AND DATA ANALYSIS FOR UNCONFINED IN-PLANE JUNCTION SHEAR STRENGTH TESTING

5.1. Materials Tested

Samples of Secugrid® 30/30 Q1 were received in April 2003. Secugrid® 30/30 Q1 is a biaxial geogrid, made from pre-stretched and molecularly aligned monolithic flat bars welded together at right angles. The characteristic product short-term tensile strength for Machine Direction [MD] and Cross-Machine Direction [XMD] is 30kN/m when tested under DIN ISO 10 319 (1996). The polymer, as specified by the manufacturer, is a white Polypropylene [PP]. The manufacturer's product properties for Secugrid® 30/30 Q1 are listed in Table 1.

5.2. Test Specimens

Test specimen positions on prepared samples were agreed with Naue Fasertechnik GmbH &Co KG and specimens were cut accordingly, Fig. 2. To test a prepared specimen it was inserted into clamps, Figs. 3 and 4, the clamps were then closed and secured, and placed into the tensile testing machine. The test was 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). 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 testing of at least 10 specimens to determine specimen variation. For the Unconfined In-plane 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.

5.3. 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 in 'Microcal Origin' plots.

5.4. Test Results

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

6. INTERPRETATION OF THE UNCONFINED IN-PLANE 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 In-plane Junction Shear Strength testing was compared to data obtained under CRS test conditions at limiting strain levels of 2%.

Test results obtained from twenty Unconfined In-plane Junction Shear Strength tests are given in Table 2.

The results for Secugrid® 30/30 Q1 showed that average maximum Unconfined In-plane Junction Shear Strength of 652 N per junction was achieved. The average Standard Deviation from twenty tests of ±29 N indicates a high rate of reproducibility for this product. As different welding positions were tested these results show that the welding process is very uniform and consistent.

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 In-plane Junction Shear Strength per cross member of 16.9 kN/m was calculated. The product strength of Secugrid® 30/30 Q1 at a limiting strain of 2% was determined to be 12.0 kN/m. Thus the Unconfined In-plane Junction Shear Strength is higher than the Unconfined In-plane Uniaxial Tensile Strength developed under working conditions.

As stated previously, more than one cross-member is operational in practice and the junctions are confined so that the operational significance of this interpretation is not considered to be important. The practical significance of these test data should be limited to the assessment of the uniformity of the welds.

7. CONCLUSIONS

Geogrid junctions produced in a variety of manufacturing processes may have multiple functions; from maintaining the geometrical shape of the geogrid during transport and installation, the transfer of stresses from the cross members into ribs, to the increase of stiffness in biaxial applications, e.g. roads, pavements, foundations, load transfer platforms, embankments. Junction shear strength has been identified as an important material property as it influences the anchorage lengths. Therefore, it is important to understand the operational behaviour of Geogrid Reinforced Soil Structures, i.e. the development of either uniaxial or biaxial loading conditions, the confining pressures on the grid and junction, the stress and strain distribution along the grid, etc.

It has been identified in this investigation that strains associated with most applications, subject to normal operational conditions, i.e. sustained or quasisustained loadings, do not exceed 1 or 2 per cent tensile strain at the Service ability Limit State. Additionally, it has been suggested that stresses are very likely to be distributed along an 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, Fig. 1. Applications where Secugrid® products are used, have a suggested minimum anchorage length or overlap of 300mm or more, which corresponds to 8 or more cross-members for Secugrid® 30/30 Q1. With the levels of loads generated per cross-member found in this test series, the In-plane Junction Shear Strength of Secugrid® 30/30 Q1 appears to be more than adequate.

Additionally, it must be appreciated that due to the test set-up and other constraining conditions these Unconfined In-plane Junction Shear Strengths are the lowest values achievable. Thus, the confined in-soil behaviour is likely to be superior.

Lastly, it is suggested that further studies be undertaken to examine the correlation between the specimen length and junction shear strength and relate these results to pull-out tests conducted in a standard manner. Additionally, 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 or integral junctions.

8. References

Bell, J.R. & Steward. J.E. (1977) Construction and observations of fabric retaining walls. Proc. Int. Conf. on the Use of Fabrics in Geotechnique, Paris, France, vo. 1, p. 123-128.

Berg, R.R., Bonaparte, R., Anderson, R.P. & Chouery, V.E. (1986) Design, construction and performance of two geogrid-reinforced soil retaining walls. Proc. 3rd Int. Conf. on Geotextiles, Vienna, Austria, vo. 2, p. 401-408.

BS 6906-1 (1987) Determination of tensile properties using a wide width strip, Part 1, BSI, UK.

BS 6906-5 (1991) Determination of creep. Part 5, BSI, UK.

BS EN 20139. Textiles Standard atmospheres for conditioning and testing, 1992.

DIN ISO 10 319 (1996) Zugversuch am breiten Streifen, Deutsches Institut für Normung, Berlin, Germany.

Fahmy, R.F.W. (1981) The prediction and measurement of the behaviour of soil-geotextile model systems acting in plain strain. Ph.D. thesis, University of Strathclyde, Glasgow, UK

GRI-GG2-87 (1987) Geogrid junction strength. Geosynthetic Research Institute, Philadelphia, USA.

ISO 9862 (1990) ISO Geotextiles. Sampling and preparation of test specimen. International Standard Organisation.

McGown, A. & Kupec, J. (2001) Secugrid® junction strength testing. Special Interim report to Naue Fasertechnik GmbH & Co KG. June 2001.

Montanelli F. & Rimoldi P. (1994) The development of Junction Strength Tests for Geosynthetics. 5th Int. Conf. on Geotextiles, Geomembranes and Related Products, Singapore, p. 445-450.

Murate, O., Uchimura, T. Ogata, k., Tayama, S., Ogisako, E., Kojima, K., Nishimura, J., Hirata, M. & Miyatake, H. (2001) Long-term performance and seismic stability of reinforced soil structures reported in Japan. Landmarks in Earth Reinforcement - Proc. Int. Symposium on Earth Reinforcement, Fukuoka, Japan, vo. 2, p. 1065-1091.

Rowe, K.R. & Li, L.A. (2001) Insights from case histories: Reinforced embankments and retaining walls. Landmarks in Earth Reinforcement - Proc. Int. Symposium on Earth Reinforcement, Fukuoka, Japan, vo. 2, p. 803-830.

Simac, M.R. Christopher, B.R. & Bonkiewicz, C. (1990) Instrumented field performance of a 6m geogrid soil wall. Proc. 4th Int. Conf. on Geotextiles, Geomembranes and Related Products, The Hague, Netherlands, vo. 1, p. 53-59.

Stolarski. G, & Gartung, E. (2001) Geogrid-reinforced road embankment over an old dump. Landmarks in Earth Reinforcement - Proc. Int. Symposium on Earth Reinforcement, Fukuoka, Japan, vo. 1, p. 281-285.

Texas Department of Transportation (2002) Section 16. Tex-621-J, Testing Geogrids. Junction Strength Testing. Department of Transportation, Texas, USA.

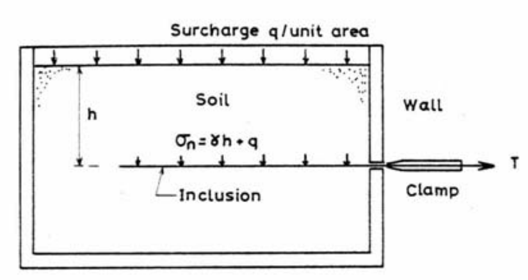
YOGARAJAH, I. (1992) Effects of construction procedures on the behaviour of geogrid reinforced soil walls. Ph.D. thesis, University of Strathclyde, Glasgow, UK.

Zornberg, J.G. & Arriaga, F. (2003) Strain distribution within geosynthetic-reinforced slopes. ASCE Journal of Geotechnical and Geoenvironmental Engineering; vo. 129, no. 1, p. 32-45.

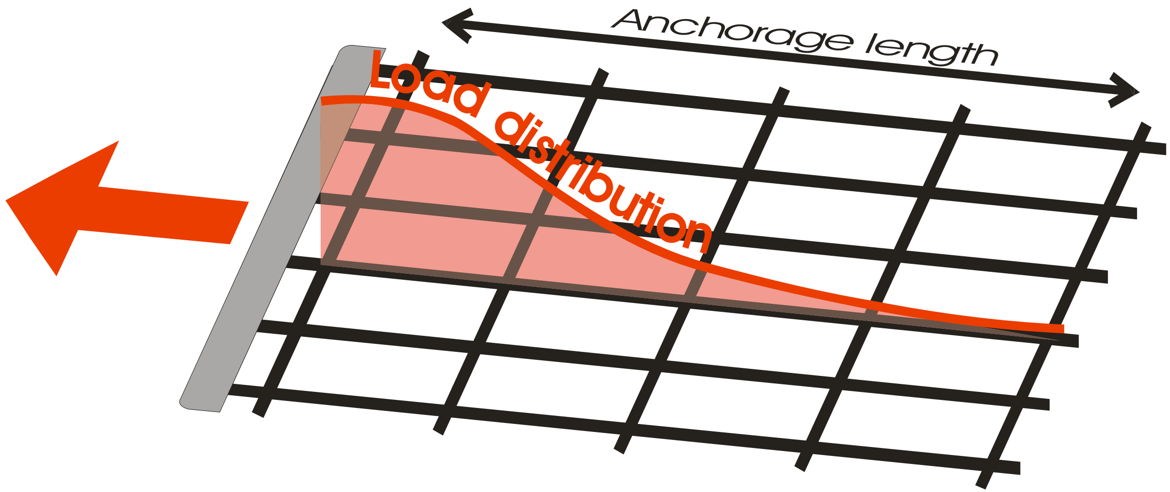
Glasgow, UK.

Monday, 07 July 2003

Mr Jan Kupec *Prof Alan McGown*



(a) Pull-out apparatus, Fahmy (1981)



(b) Load distribution

Figure 1 Load distribution along the anchorage length, Fahmy (1981) & Yogarajah (1993)

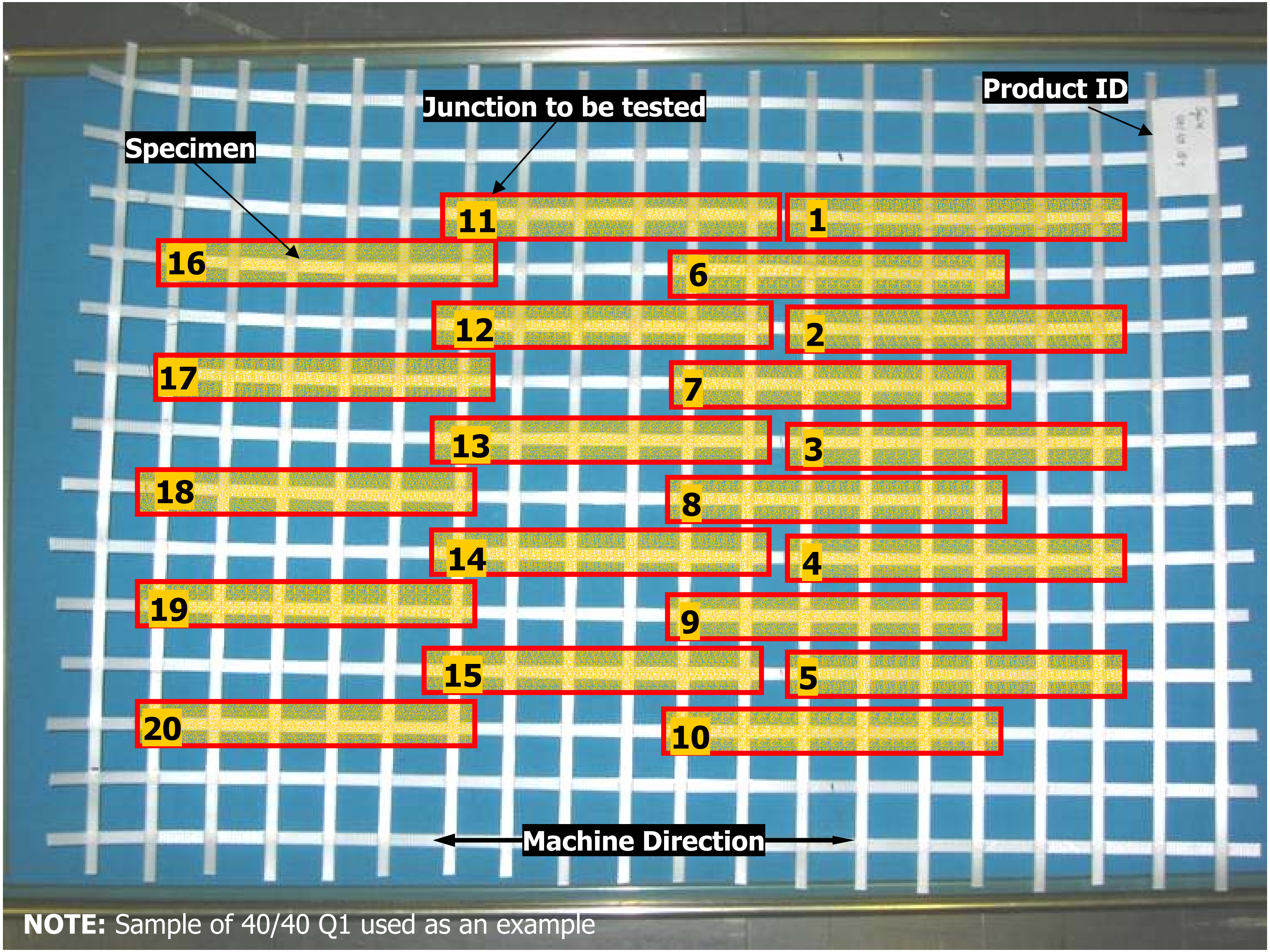
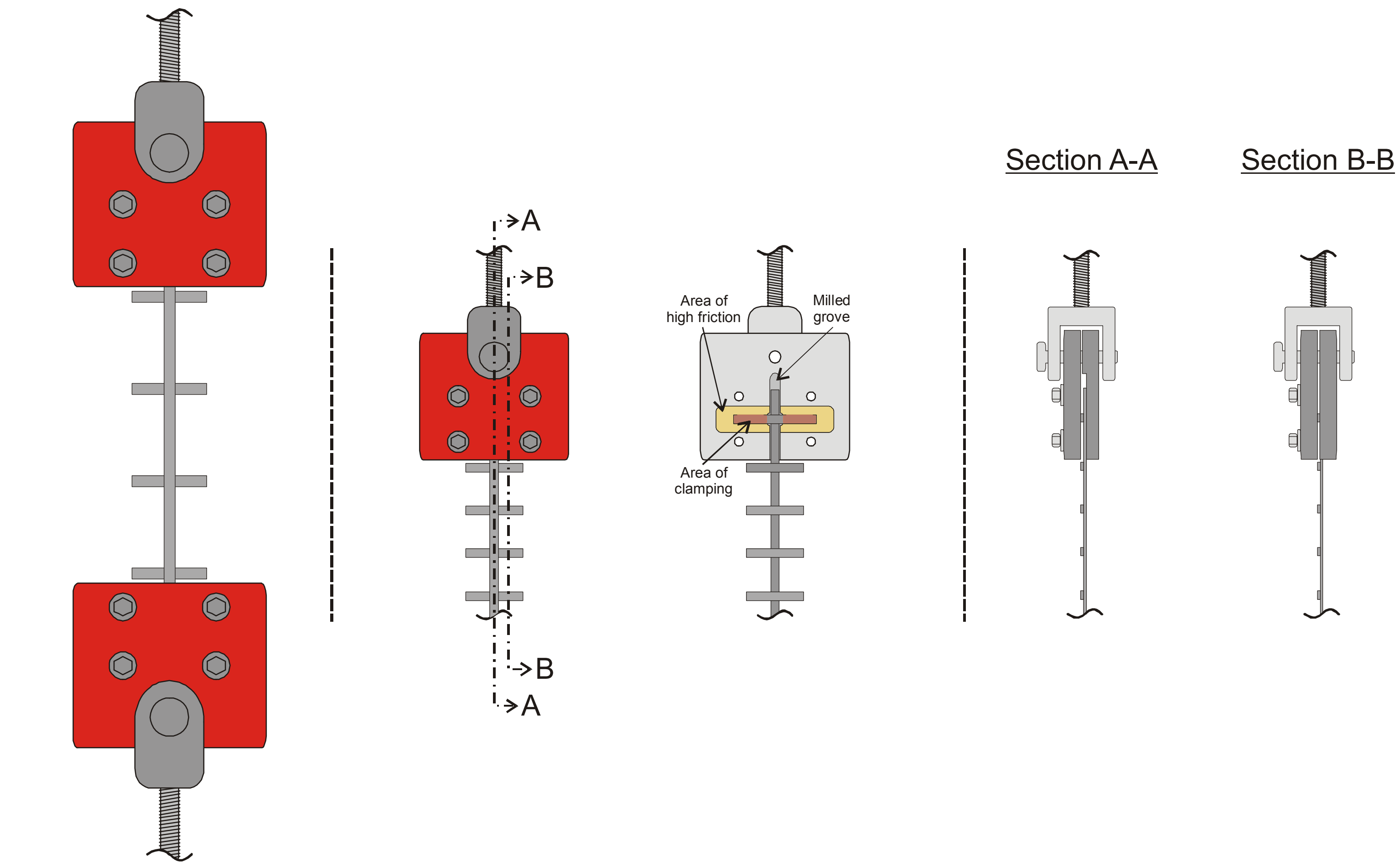


Figure 2 Position of junctions to be tested



(a) CRS single rib clamping for junction strength

(b) Clamp details

(c) Cross sections

Figure 3 Clamp for junction strength testing (technical sketches)

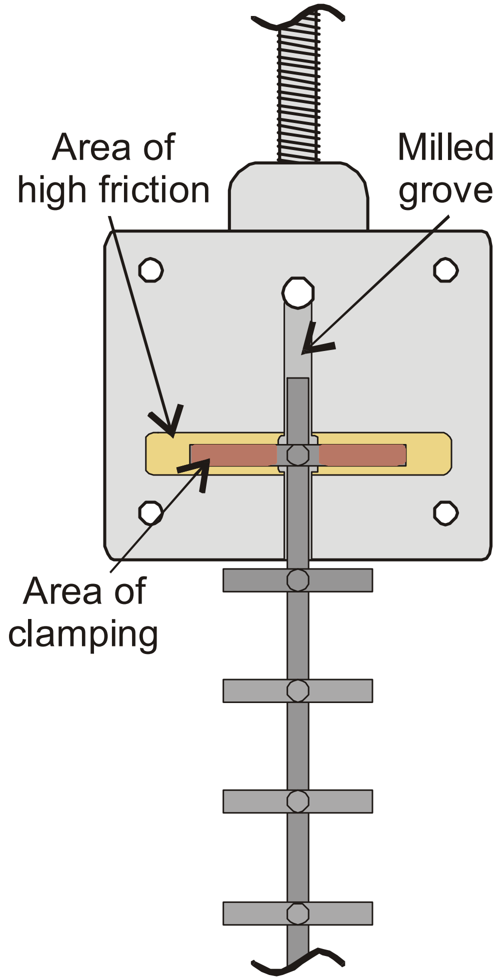
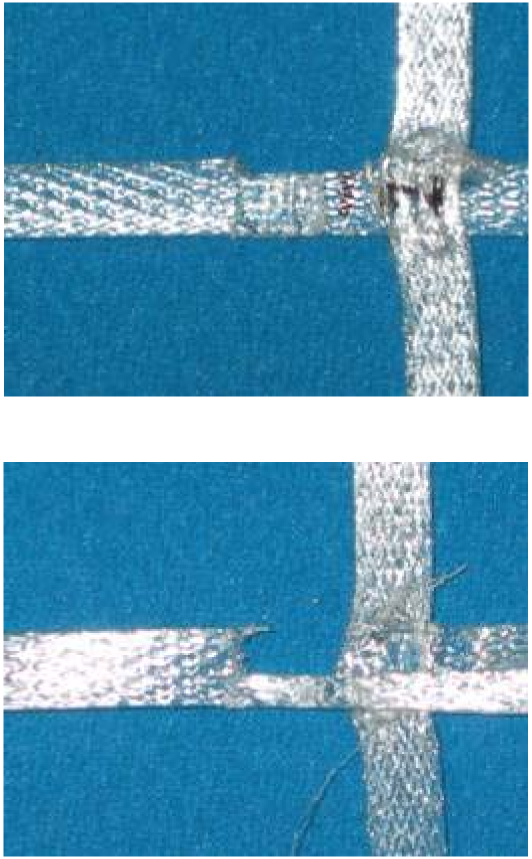
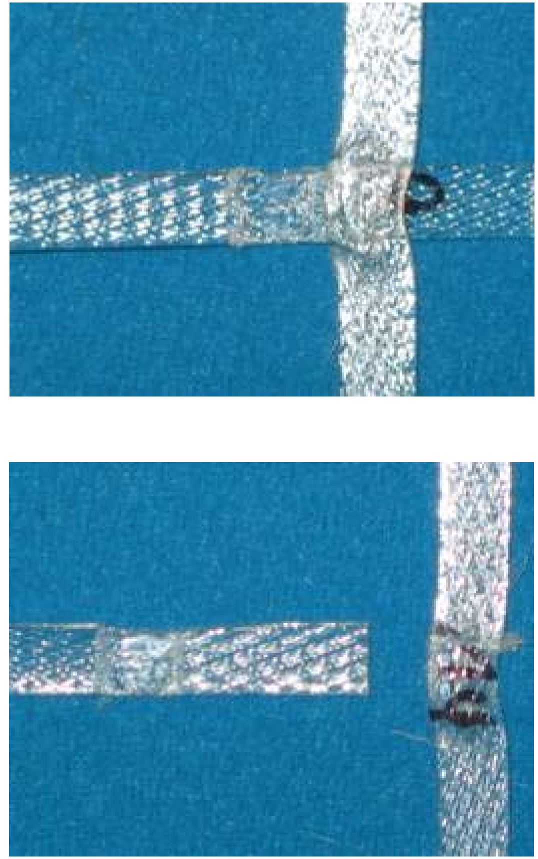


Figure 4 Clamp for junction strength testing (detail)

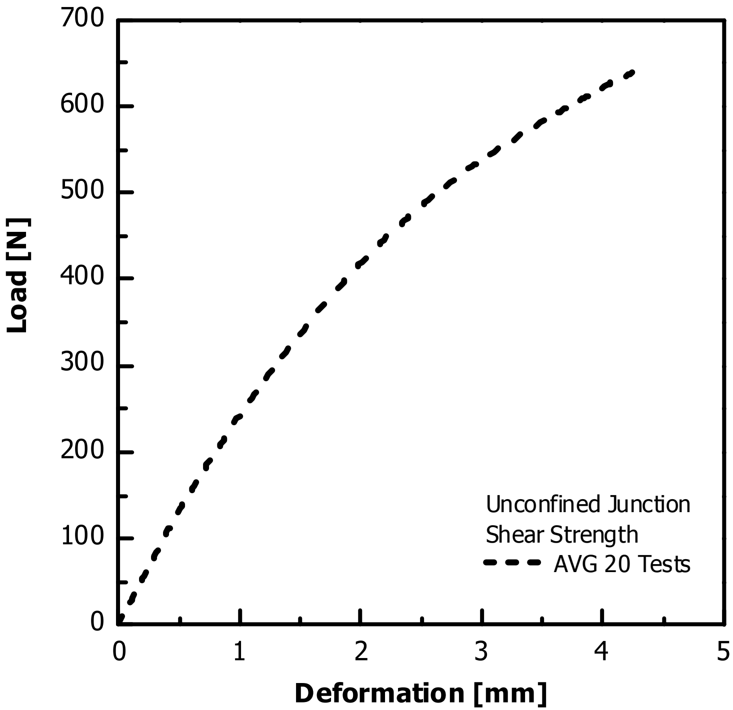


(a) Junction Rupture



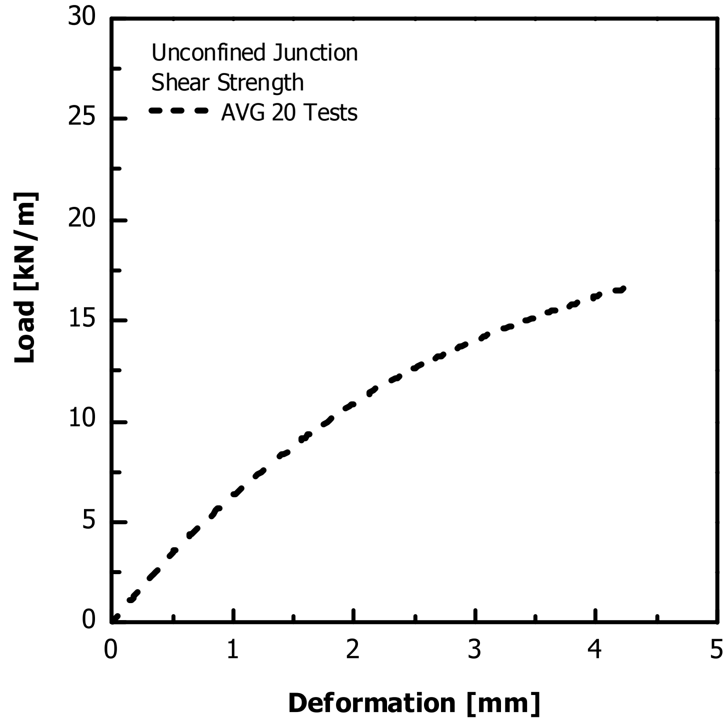
(b) Shear displacement and separation

Figure 5 Modes of failure, e.g. PET product



Maximum AVG Junction Shear Strength: 652N

(a) Load-strain behaviour in [N]



Maximum AVG Junction Shear Strength: 16.9kN/m

(b) Load-strain behaviour in [kN/m]

Figure 6 Unconfined Junction Shear Strength Tests - Secugrid® 30/30 Q1

Secugrid® 30/30 Q1

Laid geogrid made of white stretched, monolithic polypropylene flat bars with welded junctions.

Technical Data	Unconfined In-plane Uniaxial Strength[+]	Unconfined Junction Shear Strength Test
Max. Strength MD/XMD*	>30kN/m / >30kN/m	16.9kN/m / 16.9kN/m
Strain at nominal strength MD/XMD*	<8% / <8%	NA
Strength at 2% overall strain MD/XMD*	12kN/m / 12kN/m	NA
Unconfined In-plane Junction Shear Strength vs. Unconfined In-plane Uniaxial Strength at 2% overall strain	>100%	

Direct comparison possible due to test set-up

[+] According to Std-GDB Secugrid Q1, Naue Fasertechnik GmbH&Co KG, April 2003

* MD = machine direction, XMD = cross machine direction

Table 1 Product properties- Secugrid® 30/30 Q1

	Shear Strength							
	per junction			per metre+				
Deformation* [mm]	**AVG** [N]	**STDEV** [N]	**VAR** [N]	**AVG** [kN/m]	**STDEV** [kN/m]	**VAR** [kN/m]	**MIN** [kN/m]	**MAX** [kN/m]
0.00	0	0	0	0.00	0.00	0.00	0.00	0.00
0.50	127	15	6	3.31	0.38	0.15	2.61	3.93
1.00	247	15	6	6.41	0.39	0.15	5.64	6.95
1.50	341	19	9	8.86	0.49	0.24	8.13	9.84
2.00	411	26	17	10.69	0.67	0.44	9.71	11.95
2.50	473	30	24	12.29	0.79	0.62	11.16	13.92
3.00	519	36	34	13.49	0.94	0.88	11.95	15.24
3.50	563	40	42	14.64	1.05	1.10	13.39	16.55
4.00	628	39	40	16.33	1.02	1.04	14.84	17.34
4.33	652	43	48	16.94	1.12	1.24	16.16	17.73
	AVG	29	25	AVG	0.76	0.65		

+ (Junction shear strength of individual junction × ribs pro metre) / 1000

* Deformation is the sum of the rib elongation during tensile testing over the bar length and the shear distortion at the junction

Table 2 Unconfined in-plane junction shear strength testing - Secugrid® 30/30 Q1