TENAX

Technical Reference GRID-TE-4

GEOGRIDS CONSTRUCTION DAMAGE RESISTANCE

GRID-TE-4
1999

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GEOGRIDS CONSTRUCTION DAMAGE RESISTANCE

When soil, especially crushed gravel, is spread on geogrids and is compacted, geogrids suffer damage due to local punctures, indentations, abrasions, cuts and splitting due to the aggregate. Every type of geogrid suffers a different degree of damage which can be assessed by tensile tests performed on both damaged and control (undamaged) products. On this subject extensive independent test programs have been performed in the UK for evaluating the residual tensile strength of different geosynthetics after a full scale compaction damage trial. For example, full scale compaction damage trials were performed by the TRRL (Transport Road Research Lab) following the procedure set by Watts and Brady (1990) and tensile tests were performed both on the original and damaged specimens by independent laboratories. The results of these tests for several geogrids are summarized in the following tables. Table 1 contains some results of the tests performed at TRRL, as reported by Wright and Greenwood (1993), Watts and Brady (1994) and Watts and Greene (1995). All the tests reported here, have been conducted in agreement with the procedure defined by Watts and Brady (1990) and the tensile tests carried out in agreement with either BS6906 Part 1 or ISO 10319 Wide Width Tensile Test Methods and GRI-GG1 Single Rib Tensile Test Method.

In Table 1 the different installation damage resistances with limestone gravel are evident. The PET geogrid has retained a minimum of 51% of their original tensile strength, Tensar uniaxial geogrids retain a minimum of 72%, while Tenax geogrids retain a minimum of 92% of their original strength. This means that, while woven PET geogrids and cold punched integral geogrids appear to be substantially damaged by the compaction of a gravel soil, molten formed integral Tenax geogrids are only slightly affected by the compaction even of a very aggressive soil. This behaviour can be ascribed to the different manufacturing processes. In fact the molten formed geogrid process (thanks to the punching being made during extrusion) ensures continuity of the molecular chains along the ribs and through the junctions in the direction of the stresses applied during the orientation. On the other hand, the cold punching Tensar process is based on punching of a flat cold extruded sheet: this process does not allow the molecular chains to be optimally distributed and the physical structure of the material to be optimally stretched, thus causing internal stresses to the grid structure. This, in turn, produces substantial brittleness of the junctions and of the ribs which results in high damage and severe splitting during construction and installation. A proof of this is shown by the severe splitting occurring while bending a transversal bar of the Tensar geogrids. In cold environments or on aged geogrids, this behaviour is even worse.

Polyester geogrids are considerably lighter (30%) in weight than polyolephine geogrids. Moreover if we consider that most of the geogrid unit weight is given by the rib coating, it is very easy to understand why the PET geogrids can be easily damaged; they behave as thin filaments between sharp angular stones.

An easy test to evaluate the PET geogrids construction damage resistance is to verify how easy it is to cut them with a pair of scissors or to tear the mesh apart with the hands. The thin strands of woven PET geogrids are easily cut by the sharp gravel particles. The conclusion taken by Watts and Brady (1994) for the PET geogrid type is that "... it is unlikely that ... (it) would be accepted for high risk sites".

Table 1 - Results of full scale compaction damage test trial with crushed limestone gravel.

Product Name	Note	test direction: MD/TD	Control Strength at peak (kN/m)	Damaged Strength at peak (kN/m)	Residual strength, %	FSid
TENAX						
TT 201 SAMP	b	MD	57.24	54.65	95.48	1.05
TT 301 SAMP	b	MD	76.15	71.08	93.34	1.07
TT 301 SAMP	d	MD	67.52	68.72	>100	1.00
TT 401 SAMP	a	MD	83.43	83.63	>100	1.00
TT 401 SAMP	b	MD	89.84	85.47	95.14	1.05
TT 401 SAMP	c	MD	80.00	80.00	100	1.00
TT 701 SAMP	b	MD	111.11	113.57	>100	1.00
TT 701 SAMP	d	MD	112.74	110.97	98.43	1.02
LBO 220 SAMP	b	MD	21.13	21.15	>100	1.00
LBO 220 SAMP	b	TD	28.86	28.46	98.61	1.01
LBO 303 SAMP	b	MD	24.96	24.94	99.92	1.00
LBO 303 SAMP	b	TD	42.65	40.11	94.04	1.06
LBO 303 SAMP	d	MD	22.83	23.03	>100	1.00
LBO 303 SAMP	d	TD	39.89	39.28	98.47	1.02
MS 220	b	MD	14.69	14.39	97.96	1.02
MS 220	b	TD	25.31	23.40	92.45	1.08
MS 330	b	MD	22.03	21.58	97.96	1.02
MS 330	b	TD	37.96	35.10	92.45	1.08
MS 1000	b	MD	19.13	19.93	>100	1.00
MS 1000	b	TD	23.16	22.70	98.01	1.02
TENSAR						
SR 55	a	MD	55.13	39.67	71.96	1.39
SR 80	b	MD	95.92	74.05	77.20	1.30
SR 80	c	MD	79.00	64.00	81.01	1.23
SR 110	d	MD	106.01	99.83	94.17	1.06
SS2	b	MD	21.34	19.34	90.63	1.10
SS2	b	TD	34.45	29.14	84.59	1.18
SS1	b	MD	14.96	14.17	94.72	1.06
SS1	b	TD	24.03	22.21	92.43	1.08
PET GEOGRIDS						
FORTRAC 35/20-20	d	MD	39.34	29.19	74.20	1.35
FORTRAC 35/20-20	b	MD	40.02	20.39	50.95	1.96
FORTRAC 55/30-20	c	MD	57.00	33.00	57.89	1.73
FORTRAC 80/30-20	d	MD	82.85	75.19	90.75	1.10
FORTRAC 80/30-20	b	MD	79.36	60.20	75.86	1.32
FORTRAC 110/30-20	d	MD	111.94	98.99	88.43	1.13
RAUGRID 6-6/15	a	MD	62.45	41.97	67.21	1.49

Note: a) = Wright and Greenwood (1994) b) = Tenax trials (1994)
c) = Watts and Brady (1994) d) = Watts and Brady (1995).

Similar construction damage results have been obtained when the geogrids have been exposed to compaction with sand layers or clay with pebbles. The results are listed below in Table 2, with still less aggressive fill soils, the Tenax geogrids do not suffer any measurable damage, while for the other geogrid types a FSid of 1.20 is suggested.

Table 2. Construction damage test results on geogrids and different soils, Wright and Greenwood (1994).

	Residual strength, % / Fsid			
	Limestone with Shear Load	Limestone	Sand	Clay With pebbles
TENAX TT 401 SAMP	99.06 1.01	100 1.00	100 1.00	100 1.00
TENSAR SR 55	64.21 1.56	71.96 1.39	94.23 1.06	83.09 1.20
PET GEOGRID	92.78 1.08	67.21 1.49	94.30 1.06	93.92 1.07

TENAX CONSTRUCTION DAMAGE TRIAL

The construction damage trials, simulating a full scale compaction have been conducted using a sharp angular crushed stone aggregate having granite geomorphology. The dimension of the aggregate were mainly ranging between 60 and 40 mm (BS 1377:92).

The soil was spread on a runway 2.5 m wide by 15 m long and then compacted. The compaction was performed by means of a heavy duty vibrator roller. The compaction plant was a 30 ton Simesa tandem type, front and rear vibrator drum having the specifications listed in Table 3.

Table 3: Simesa vibratory compactor specification

	Front Roller	Rear Roller
Drum width	1.75 m	1.75 m
Drum diameter	1.40 m	1.40 m
Static load	7000 kg	7000 kg
Static load	4000 kg/m	4000 kg/m
Centrifugal load	8000 kg	8000 kg
Total load	15000 kg	15000 kg
Total load	8570 kg/m	8570 kg/m

The compaction method used is in accordance with the UK specification for highway works as given in Table 6/4, Method 2 for well graded granular material

(Department of Transportation 1991, volume 1, page 52). In accordance with this specification, the required number of drum passes "N" to obtain a well compacted layer having a thickness "D" of 225 mm is four.

For these compaction test trials it has been decided to achieve the compacted thickness of 175 mm with 6 drum passes. Thus the method applied was more severe than standard compaction for highway works (Table 4), both in the number of passes and the final thickness. The target resulting thickness was 175 mm with a density of 95% of the optimum Proctor (void ratio of about 5% or less).

Table 4: Highway specification and actual compaction test.

	D.O.T. Specification	Tenax Trial
Compacted Thickness	225 mm	175 mm
N. of Passes	4	6
Mass per Meter Width	3600÷4300 kg/m	4000 kg/m
Total load	-	8570 kg/m

The geogrid specimens were cut 2 m long by 1 m wide and installed transversally to the trial runway on a previously compacted 175 mm gravel bed. About 16 geosynthetics have been installed side to side. The positions have been randomly chosen. The compacted area was about 1.8 m wide x 15 m long.

After the geosynthetics placement, a layer of crushed stone was placed, spread and compacted, as previously indicated. After compaction, the specimens were carefully exhumed for damage identification and testing.

The tensile tests have been performed in accordance to GRI-GG1 single rib test method and ISO 10319 wide width tensile test method both on the control and damaged geogrids. The single rib tensile tests on the damaged products have been performed only on the visually damaged (but not broken) ribs. The results are reported in tables 5, 6, 7, and 8.

The overall residual strength and strain percentages and relate Installation Damage Safety Factors **FSid** have been calculated by comparing the damaged tensile results with the same test performed on the control specimens.

Tab. 5 - Wide width tensile test results (ISO 10319) of full-scale compaction damage test trial with crushed granite gravel, Tenax report

Product Name	Unit weight (g/m^2)	test direction MD/TD	Control /Damaged	Strength at 2 % strain (kN/m)	Strength at 5 % strain (kN/m)	Strength at peak (kN/m)	Strain at peak (%)
TENAX LBO 201 SAMP	265	MD	C	5.58	10.97	17.46	15.60
TENAX LBO 201 SAMP	265	MD	D	5.43	11.06	18.07	15.90
TENAX LBO 201 SAMP	265	TD	C	8.01	16.63	27.97	13.20
TENAX LBO 201 SAMP	265	TD	D	8.78	17.46	26.17	10.40
TENAX LBO 220 SAMP	280	MD	C	9.36	16.27	19.62	8.40
TENAX LBO 220 SAMP	280	MD	D	8.99	16.47	22.09	10.80
TENAX LBO 220 SAMP	280	TD	C	11.37	20.52	27.32	9.50
TENAX LBO 220 SAMP	280	TD	D	11.33	20.65	27.48	9.30
TENAX LBO 301 SAMP	391	MD	C	8.82	16.54	24.45	14.60
TENAX LBO 301 SAMP	391	MD	D	9.18	16.55	24.01	14.40
TENAX LBO 301 SAMP	391	TD	C	14.86	27.73	40.55	10.90
TENAX LBO 301 SAMP	391	TD	D	14.95	27.56	39.09	10.30
TENAX LBO 303 SAMP	423	MD	C	10.81	19.11	26.31	13.50
TENAX LBO 303 SAMP	423	MD	D	10.74	19.00	26.02	12.60
TENAX LBO 303 SAMP	423	TD	C	16.98	30.30	42.10	9.50
TENAX LBO 303 SAMP	423	TD	D	16.45	30.47	39.65	8.90
TENAX LBO 401 SAMP	659	MD	C	14.16	24.94	35.07	12.20
TENAX LBO 401 SAMP	659	MD	D	14.43	25.18	33.59	11.10
TENAX LBO 401 SAMP	659	TD	C	17.04	31.09	42.04	9.10
TENAX LBO 401 SAMP	659	TD	D	17.31	30.78	39.55	8.20
TENAX MS 1000	271	MD	C	7.41	12.96	18.74	11.90
TENAX MS 1000	271	MD	D	7.42	13.05	20.19	13.30
TENAX MS 1000	271	TD	C	10.33	19.53	22.91	7.00
TENAX MS 1000	271	TD	D	10.47	19.48	24.37	7.80
TENAX MS 220	213	MD	C	5.46	10.32	15.13	11.70
TENAX MS 220	213	MD	D	5.27	10.09	14.56	11.00
TENAX MS 220	213	TD	C	10.52	19.53	25.13	8.80
TENAX MS 220	213	TD	D	9.52	17.52	22.35	8.30
TENAX TT 201 SAMP	455	MD	C	17.91	32.46	54.61	11.10
TENAX TT 201 SAMP	455	MD	D	16.99	31.37	49.29	9.50
TENAX TT 301 SAMP	660	MD	C	25.11	45.31	71.02	12.60
TENAX TT 301 SAMP	660	MD	D	22.78	42.33	65.70	10.50
TENAX TT 401 SAMP	839	MD	C	32.90	55.64	91.52	13.60
TENAX TT 401 SAMP	839	MD	D	29.75	53.83	86.47	12.60
TENAX TT 701 SAMP	1054	MD	C	41.68	72.49	113.83	12.90
TENAX TT 701 SAMP	1054	MD	D	44.13	74.60	114.06	11.90
TENSAR SS-1	212	MD	C	6.87	12.08	16.05	17.70
TENSAR SS-1	212	MD	D	6.58	11.68	15.13	13.90
TENSAR SS-1	212	TD	C	11.09	19.45	24.77	11.00
TENSAR SS-1	212	TD	D	10.61	19.11	22.37	7.40
TENSAR SS-2	292	MD	C	10.38	18.35	22.53	12.10
TENSAR SS-2	292	MD	D	9.49	17.32	22.13	13.00
TENSAR SS-2	292	TD	C	17.45	30.23	35.80	8.30
TENSAR SS-2	292	TD	D	16.71	28.09	30.70	6.00
TENSAR SR 80	712	MD	C	35.97	61.81	98.46	11.40
TENSAR SR 80	712	MD	D	32.36	57.99	68.67	6.90
FORTRAC 35/20-30	243	MD	C	7.61	12.32	40.02	19.60
FORTRAC 35/20-30	243	MD	D	6.40	10.75	20.39	13.20
FORTRAC 80/20-30	440	MD	C	14.36	20.75	79.36	26.60
FORTRAC 80/20-30	440	MD	D	13.73	20.10	60.20	21.80

Tab. 6 - Single rib tensile test results (GRI-GG1) of full scale compaction damage test trial with crushed granite gravel, Tenax report

Product Name	Unit weight (g/m^2)	test direction MD/TD	Control / Damaged	Strength at 2 % strain (kN/m)	Strength at 5 % strain (kN/m)	Strength at peak (kN/m)	Strain at peak (%)
TENAX LBO 201 SAMP	265	MD	C	5.59	10.82	16.84	14.30
TENAX LBO 201 SAMP	265	MD	D	5.50	10.83	17.38	14.70
TENAX LBO 201 SAMP	265	TD	C	8.71	16.95	26.57	12.70
TENAX LBO 201 SAMP	265	TD	D	8.54	17.06	25.40	9.90
TENAX LBO 220 SAMP	280	MD	C	8.50	15.94	21.13	10.60
TENAX LBO 220 SAMP	280	MD	D	8.06	15.40	21.15	11.80
TENAX LBO 220 SAMP	280	TD	C	11.72	21.19	28.86	9.90
TENAX LBO 220 SAMP	280	TD	D	11.68	20.97	28.46	9.80
TENAX LBO 301 SAMP	391	MD	C	8.31	15.86	22.93	13.80
TENAX LBO 301 SAMP	391	MD	D	8.51	16.07	22.98	13.20
TENAX LBO 301 SAMP	391	TD	C	13.37	25.99	40.31	11.60
TENAX LBO 301 SAMP	391	TD	D	13.22	25.86	38.04	10.10
TENAX LBO 303 SAMP	423	MD	C	9.71	17.98	24.96	13.70
TENAX LBO 303 SAMP	423	MD	D	9.71	17.95	24.94	13.40
TENAX LBO 303 SAMP	423	TD	C	16.08	30.08	42.65	12.40
TENAX LBO 303 SAMP	423	TD	D	16.26	30.54	40.11	9.30
TENAX LBO 401 SAMP	659	MD	C	13.29	24.00	34.71	12.80
TENAX LBO 401 SAMP	659	MD	D	14.11	24.49	33.82	12.00
TENAX LBO 401 SAMP	659	TD	C	16.88	30.35	42.61	10.20
TENAX LBO 401 SAMP	659	TD	D	17.25	30.61	41.09	9.50
TENAX MS 1000	271	MD	C	5.87	11.25	19.13	14.50
TENAX MS 1000	271	MD	D	6.45	12.20	19.93	13.80
TENAX MS 1000	271	TD	C	10.57	19.30	23.16	7.00
TENAX MS 1000	271	TD	D	10.15	18.72	22.70	7.10
TENAX MS 220	213	MD	C	5.28	9.85	14.69	12.00
TENAX MS 220	213	MD	D	4.54	9.14	14.39	11.80
TENAX MS 220	213	TD	C	9.40	18.01	25.31	10.50
TENAX MS 220	213	TD	D	9.25	17.95	23.40	8.10
TENAX TT 201 SAMP	455	MD	C	17.68	32.14	57.24	12.90
TENAX TT 201 SAMP	455	MD	D	18.01	32.10	54.65	11.20
TENAX TT 301 SAMP	660	MD	C	23.51	42.37	76.15	13.60
TENAX TT 301 SAMP	660	MD	D	23.30	42.75	71.08	11.70
TENAX TT 401 SAMP	839	MD	C	28.17	50.74	89.84	14.00
TENAX TT 401 SAMP	839	MD	D	29.35	52.03	85.47	12.60
TENAX TT 701 SAMP	1054	MD	C	39.47	68.74	111.11	13.00
TENAX TT 701 SAMP	1054	MD	D	37.12	68.46	113.57	13.60
TENSAR SS-1	212	MD	C	7.00	12.08	14.96	10.30
TENSAR SS-1	212	MD	D	6.40	11.37	14.17	10.30
TENSAR SS-1	212	TD	C	11.19	19.94	24.03	8.90
TENSAR SS-1	212	TD	D	10.47	18.73	22.21	8.10
TENSAR SS-2	292	MD	C	10.14	17.64	21.34	11.10
TENSAR SS-2	292	MD	D	9.63	16.87	19.34	9.20
TENSAR SS-2	292	TD	C	16.34	29.61	34.45	8.40
TENSAR SS-2	292	TD	D	15.44	28.09	29.14	6.40
TENSAR SR 80	700	MD	C	32.90	57.92	95.92	12.50
TENSAR SR 80	700	MD	D	31.85	56.37	74.05	7.90

Tab. 7 - Wide width tensile (ISO 10319) residual properties and installation safety factors FSid of full scale compaction damage test trial with crushed granite gravel, Tenax report

Product Name	**Unit weight (g/m^2)**	**test direction : MD/TD**	**Residual strength, % or FSid**	**Strength at 2 % strain**	**Strength at 5 % strain**	**Strength at peak**	**strain at peak**
TENAX LBO 201 SAMP	265	MD	Residual, %	97.3	100.8	103.5	101.9
TENAX LBO 201 SAMP	265	MD	FSid	1.03	1.00	1.00	1.00
TENAX LBO 201 SAMP	265	TD	Residual, %	109.6	105.0	93.6	78.8
TENAX LBO 201 SAMP	265	TD	FSid	1.00	1.00	1.07	1.27
TENAX LBO 220 SAMP	280	MD	Residual, %	96.05	101.23	112.59	128.57
TENAX LBO 220 SAMP	280	MD	FSid	1.04	1.00	1.00	1.00
TENAX LBO 220 SAMP	280	TD	Residual, %	99.65	100.63	100.59	97.89
TENAX LBO 220 SAMP	280	TD	FSid	1.00	1.00	1.00	1.02
TENAX LBO 301 SAMP	391	MD	Residual, %	104.1	100.1	98.2	98.6
TENAX LBO 301 SAMP	391	MD	FSid	1.00	1.00	1.02	1.01
TENAX LBO 301 SAMP	391	TD	Residual, %	100.6	99.4	96.4	94.5
TENAX LBO 301 SAMP	391	TD	FSid	1.00	1.01	1.04	1.06
TENAX LBO 303 SAMP	423	MD	Residual, %	99.4	99.4	98.9	93.3
TENAX LBO 303 SAMP	423	MD	FSid	1.01	1.01	1.01	1.07
TENAX LBO 303 SAMP	423	TD	Residual, %	96.9	100.6	94.2	93.7
TENAX LBO 303 SAMP	423	TD	FSid	1.03	1.00	1.06	1.07
TENAX LBO 401 SAMP	659	MD	Residual, %	101.9	101.0	95.8	91.0
TENAX LBO 401 SAMP	659	MD	FSid	1.00	1.00	1.04	1.10
TENAX LBO 401 SAMP	659	TD	Residual, %	101.6	99.0	94.1	90.1
TENAX LBO 401 SAMP	659	TD	FSid	1.00	1.01	1.06	1.11
TENAX MS 1000	271	MD	Residual, %	100.1	100.7	107.7	111.8
TENAX MS 1000	271	MD	FSid	1.00	1.00	1.00	1.00
TENAX MS 1000	271	TD	Residual, %	101.4	99.7	106.4	111.4
TENAX MS 1000	271	TD	FSid	1.00	1.00	1.00	1.00
TENAX MS 220	213	MD	Residual, %	96.5	97.8	96.2	94.0
TENAX MS 220	213	MD	FSid	1.04	1.02	1.04	1.06
TENAX MS 220	213	TD	Residual, %	90.5	89.7	88.9	94.3
TENAX MS 220	213	TD	FSid	1.11	1.11	1.12	1.06
TENAX TT 201 SAMP	455	MD	Residual, %	94.86	96.64	90.26	85.59
TENAX TT 201 SAMP	455	MD	FSid	1.05	1.03	1.11	1.17
TENAX TT 301 SAMP	660	MD	Residual, %	90.7	93.4	92.5	83.3
TENAX TT 301 SAMP	660	MD	FSid	1.10	1.07	1.08	1.20
TENAX TT 401 SAMP	839	MD	Residual, %	90.4	96.7	94.5	92.6
TENAX TT 401 SAMP	839	MD	FSid	1.11	1.03	1.06	1.08
TENAX TT 701 SAMP	1054	MD	Residual, %	105.9	102.9	100.2	92.2
TENAX TT 701 SAMP	1054	MD	FSid	1.00	1.00	1.00	1.08
TENSAR SS-1	212	MD	Residual, %	95.8	96.7	94.3	78.5
TENSAR SS-1	212	MD	FSid	1.04	1.03	1.06	1.27
TENSAR SS-1	212	TD	Residual, %	95.7	98.3	90.3	67.3
TENSAR SS-1	212	TD	FSid	1.05	1.02	1.11	1.49
TENSAR SS-2	292	MD	Residual, %	91.4	94.4	98.2	107.4
TENSAR SS-2	292	MD	FSid	1.09	1.06	1.02	1.00
TENSAR SS-2	292	TD	Residual, %	95.8	92.9	85.8	72.3
TENSAR SS-2	292	TD	FSid	1.04	1.08	1.17	1.38
TENSAR SR 80	712	MD	Residual, %	90.0	93.8	69.7	60.5
TENSAR SR 80	712	MD	FSid	1.11	1.07	1.43	1.65
FORTRAC 35/20-30	243	MD	Residual, %	84.1	87.3	50.9	67.3
FORTRAC 35/20-30	243	MD	FSid	1.19	1.15	1.96	1.48
FORTRAC 80/20-30	440	MD	Residual, %	95.6	96.9	75.9	82.0
FORTRAC 80/20-30	440	MD	FSid	1.05	1.03	1.32	1.22

Tab. 8 - Single rib tensile (GRI-GG1) residual properties and installation safety factors FSid of full scale compaction damage test trial with crushed granite gravel, Tenax report

Product Name	**Unit weight (g/m^2)**	**test direction : MD/TD**	**Residual strength, % or FSid**	**Strength at 2 % strain**	**Strength at 5 % strain**	**Strength at peak**	**strain at peak**
TENAX LBO 201 SAMP	265	MD	Residual, %	98.4	100.1	103.2	102.8
TENAX LBO 201 SAMP	265	MD	FSid	1.02	1.00	1.00	1.00
TENAX LBO 201 SAMP	265	TD	Residual, %	98.0	100.6	95.6	78.0
TENAX LBO 201 SAMP	265	TD	FSid	1.02	1.00	1.05	1.28
TENAX LBO 220 SAMP	280	MD	Residual, %	94.82	96.61	100.09	111.32
TENAX LBO 220 SAMP	280	MD	FSid	1.05	1.04	1.00	1.00
TENAX LBO 220 SAMP	280	TD	Residual, %	99.66	98.96	98.61	98.99
TENAX LBO 220 SAMP	280	TD	FSid	1.00	1.01	1.01	1.01
TENAX LBO 301 SAMP	391	MD	Residual, %	102.4	101.3	100.2	95.7
TENAX LBO 301 SAMP	391	MD	FSid	1.00	1.00	1.00	1.05
TENAX LBO 301 SAMP	391	TD	Residual, %	98.9	99.5	94.4	87.1
TENAX LBO 301 SAMP	391	TD	FSid	1.01	1.01	1.06	1.15
TENAX LBO 303 SAMP	423	MD	Residual, %	100.0	99.8	99.9	97.8
TENAX LBO 303 SAMP	423	MD	FSid	1.00	1.00	1.00	1.02
TENAX LBO 303 SAMP	423	TD	Residual, %	101.1	101.5	94.0	75.0
TENAX LBO 303 SAMP	423	TD	FSid	1.00	1.00	1.06	1.33
TENAX LBO 401 SAMP	659	MD	Residual, %	106.2	102.0	97.4	93.8
TENAX LBO 401 SAMP	659	MD	FSid	1.00	1.00	1.03	1.07
TENAX LBO 401 SAMP	659	TD	Residual, %	102.2	100.9	96.4	93.1
TENAX LBO 401 SAMP	659	TD	FSid	1.00	1.00	1.04	1.07
TENAX MS 1000	271	MD	Residual, %	109.9	108.4	104.2	95.2
TENAX MS 1000	271	MD	FSid	1.00	1.00	1.00	1.05
TENAX MS 1000	271	TD	Residual, %	96.0	97.0	98.0	101.4
TENAX MS 1000	271	TD	FSid	1.04	1.03	1.02	1.00
TENAX MS 220	213	MD	Residual, %	86.0	92.8	98.0	98.3
TENAX MS 220	213	MD	FSid	1.16	1.08	1.02	1.02
TENAX MS 220	213	TD	Residual, %	98.4	99.7	92.5	77.1
TENAX MS 220	213	TD	FSid	1.02	1.00	1.08	1.30
TENAX TT 201 SAMP	455	MD	Residual, %	101.87	99.88	95.48	86.82
TENAX TT 201 SAMP	455	MD	FSid	1.00	1.00	1.05	1.15
TENAX TT 301 SAMP	660	MD	Residual, %	99.1	100.9	93.3	86.0
TENAX TT 301 SAMP	660	MD	FSid	1.01	1.00	1.07	1.16
TENAX TT 401 SAMP	839	MD	Residual, %	104.2	102.5	95.1	90.0
TENAX TT 401 SAMP	839	MD	FSid	1.00	1.00	1.05	1.11
TENAX TT 701 SAMP	1054	MD	Residual, %	94.0	99.6	102.2	104.6
TENAX TT 701 SAMP	1054	MD	FSid	1.06	1.00	1.00	1.00
TENSAR SS-1	212	MD	Residual, %	91.4	94.1	94.7	100.0
TENSAR SS-1	212	MD	FSid	1.09	1.06	1.06	1.00
TENSAR SS-1	212	TD	Residual, %	93.6	93.9	92.4	91.0
TENSAR SS-1	212	TD	FSid	1.07	1.06	1.08	1.10
TENSAR SS-2	292	MD	Residual, %	95.0	95.6	90.6	82.9
TENSAR SS-2	292	MD	FSid	1.05	1.05	1.10	1.21
TENSAR SS-2	292	TD	Residual, %	94.5	94.9	84.6	76.2
TENSAR SS-2	292	TD	FSid	1.06	1.05	1.18	1.31
TENSAR SR 80	700	MD	Residual, %	96.8	97.3	77.2	63.2
TENSAR SR 80	700	MD	FSid	1.03	1.03	1.30	1.58

Because all of the geogrids tested are composed of ribs, the damage identification has been performed by identifying the overall number of MD and TD ribs and the number of broken and damaged ribs in terms of absolute and relative number. Because the uniaxially oriented geogrids are all composed of HDPE, it has been decided to evaluate the number of damaged ribs equal to 10% since this number fit within the observations made (table 9).

Tab. 9 - Visual observation on the biaxial geogrids after the full scale compaction damage test trial with crushed granite gravel, Tenax report

Product Name		**N. of Geogrid Ribs**	**Damaged Ribs**	**Broken Ribs**	**Undamaged Ribs, %**	**Damaged Ribs, %**	**Broken Ribs, %**
TENAX LBO201 SAMP	MD	35	87	1	95.94	4.01	0.05
TENAX LBO201 SAMP	TD	31	136	4	93.55	6.27	0.18
TENAX LBO201 SAMP	Overall	2'170	223	5	89.49	10.28	0.23
TENAX LBO301SAMP	MD	37	87	1	95.43	4.52	0.05
TENAX LBO301SAMP	TD	26	84	1	95.58	4.37	0.05
TENAX LBO301SAMP	Overall	1'924	171	2	91.01	8.89	0.10
TENAX LBO303 SAMP	MD	38	155	5	91.90	7.84	0.25
TENAX LBO303 SAMP	TD	26	150	3	92.26	7.59	0.15
TENAX LBO303 SAMP	Overall	1976	305	8	84.16	15.44	0.40
TENAX LBO401 SAMP	MD	45	21	0	99.20	0.80	0.00
TENAX LBO401 SAMP	TD	29	29	0	98.89	1.11	0.00
TENAX LBO401 SAMP	Overall	2610	50	0	98.08	1.92	0.00
TENAX MS220	MD	58	165	5	96.81	3.09	0.09
TENAX MS220	TD	46	249	10	95.15	4.67	0.19
TENAX MS220	Overall	5336	414	15	91.96	7.76	0.28
TENAX MS1000	MD	35	152	0	92.76	7.24	0.00
TENAX MS1000	TD	30	170	0	91.90	8.10	0.00
TENAX MS1000	Overall	2100	322	0	84.67	15.33	0.00
TENSAR SS1	MD	26	84	12	96.52	3.05	0.44
TENSAR SS1	TD	53	95	6	96.34	3.45	0.22
TENSAR SS1	Overall	2756	179	18	92.85	6.49	0.65
TENSAR SS2	MD	38	60	24	96.93	2.19	0.88
TENSAR SS2	TD	36	180	35	92.14	6.58	1.28
TENSAR SS2	Overall	2736	240	59	89.07	8.77	2.16

SYNERGY BETWEEN LONG TERM LOADS AND INSTALLATION DAMAGE

It is interesting to verify if the damage inferred during the installation may affect the long term behaviour of the Tenax geogrids.

Hereby presented is long term creep test data on construction damaged Tenax TT SAMP. The enclosed tests were performed on the TENAX TT 301 SAMP and TT 701 SAMP that have been independently exposed by the TRL UK to installation damage with sharp angular crushed stone as a fill soil (Watts and Greene, 1995).

The creep tests in agreement with ASTM D 5262, have been performed at 20°C with 40% load ratio as determined by the corresponding BS6906:1 wide width tests performed on the control specimen. The creep tests have reached 20,000 hours and are still running.
The tests have shown only minor variations after 20,000 hours (1.3%) between the mean strain of the damaged specimens versus the control specimens, as shown in table 10 and 11 and corresponding figure 1 and 2.

Table 10: Synergy between long term loads and installation damage at 1,000 hours

	Creep Strain at 1,000 hours,		**Mean Strain,**	**Delta**
	%	**%**	**%**	**%**
TENAX TT 301 SAMP				
REFERENCE TEST N. 75/91, 24/92	8.2	7.8	8.00	
DAMAGE TEST N. 180/92, 181/92	7.9	8.2	8.05	0.6
TENAX TT 701 SAMP				
REFERENCE TEST N. 32/92	7.75		7.75	
DAMAGE TEST N. 182/92, 183/92	7.55	8.05	7.80	0.6
Note: Test performed at 40% loading at 20°C.				

Table 11: Synergy between long term loads and installation damage at 20,000 hours

	Creep Strain at 20,000 hours,		**Mean Strain,**	**Delta**
	%	**%**	**%**	**%**
TENAX TT 301 SAMP				
REFERENCE TEST N. 75/91, 24/92	9.20	9.25	9.22	
DAMAGE TEST N. 180/92, 181/92	8.90	9.10	9.0	1.3
TENAX TT 701 SAMP				
REFERENCE TEST N. 32/92	8.70		8.70	
DAMAGE TEST N. 182/92, 183/92	9.00	8.45	8.72	0.3
Note: Test performed at 40% loading at 20°C.				

Thus, for the Tenax geogrids, it is safe to use the factor of safety for installation damages FSid determined by the means of short term testing. For other HDPE geogrids this conclusion can not be taken, being the damages measured much greater.

One more remark regarding PET geogrids that base their long term design strength on creep rupture analysis and not on creep strain analysis. We doubt that their predictions are accurate due to the level of measured damages of FSid up to 2.0 and to the fact that damages are mainly shown at failure point; thus, the Time-to-Rupture may be sensibly reduced and a FSid of 2.0 may not be conservative. Moreover the damage is also in the geogrid coating thus the exposure of the PET filaments to high and low pH is largely increased, and thus their durability influenced.

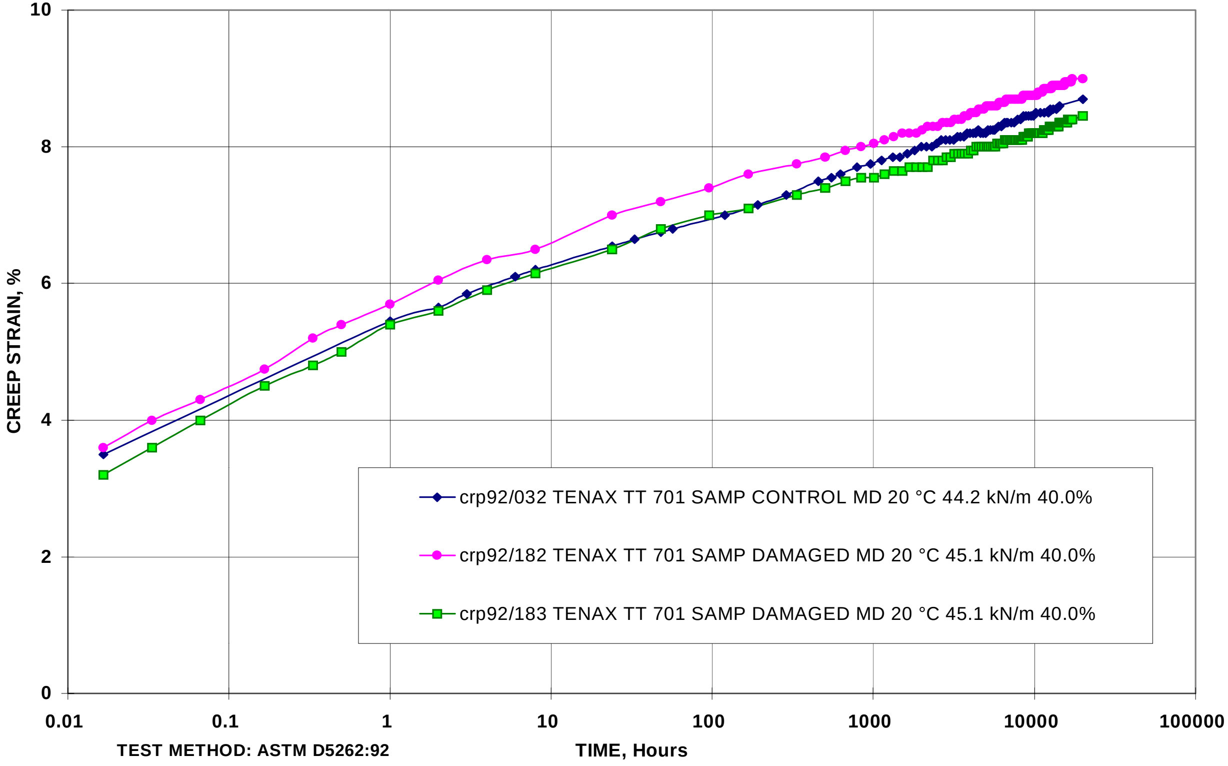

Figure 1: Tensile creep test on control and damaged specimens for Tenax TT 701 SAMP.

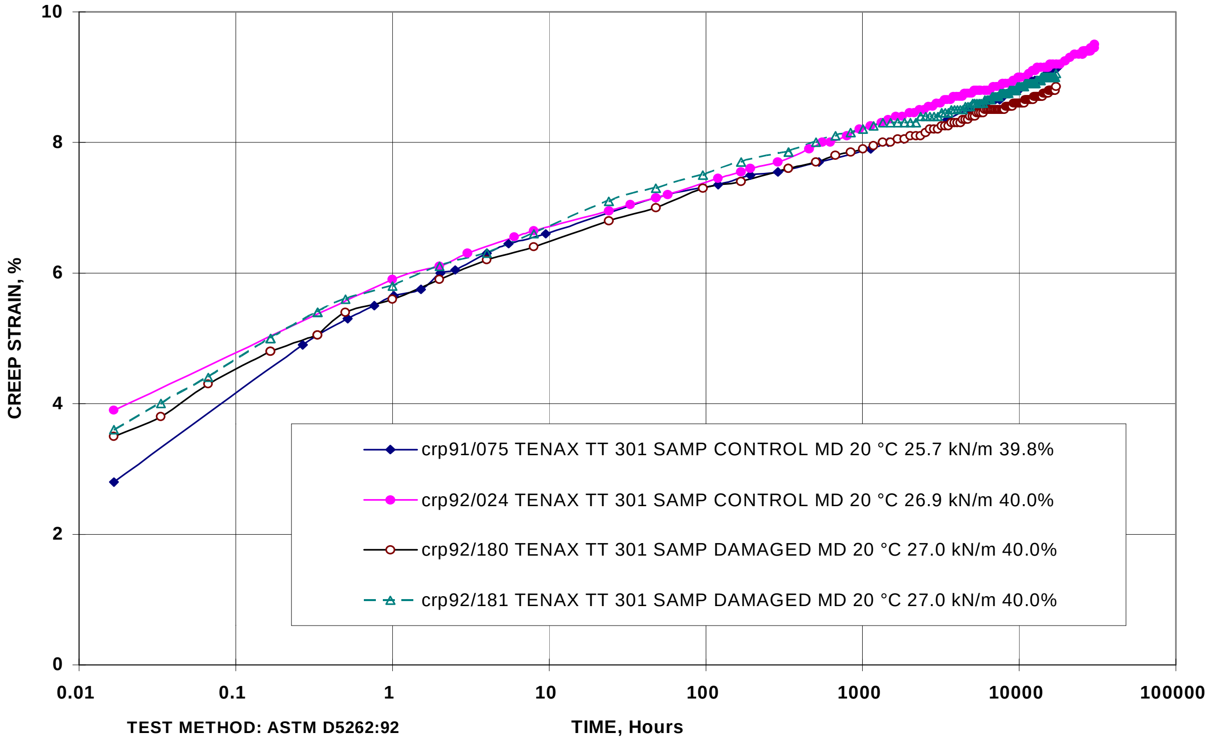

Figure 2: Tensile creep test on control and damaged specimens for Tenax TT 301 SAMP.

CONCLUSIONS

From the analysis of Table 1 it is possible to see that Tenax trial method yields conservative results for all the geogrids tested (higher damage). The higher damage to the geogrids was probably due to the more severe nature of the granite aggregate material (sharpness and hardness), to the higher compaction energy applied, and to the lower thickness of the fill layer.

Generally speaking a FSid of 1.05 for construction damages can be used for any Tenax geogrid, any type of soil and with severe installation equipment and compaction. The damages due to installation with limestone gravel, does not affect the long-term properties of the Tenax geogrids, thus no other safety factors may be needed.

For Tensar geogrids, a FSid ranging from 1.10 to 1.15 for construction damages can be used for biaxial geogrid and a FSid ranging from 1.30 to 1.50 for construction damages can be used for uniaxial geogrid when gravel soil is used.

For PET geogrids, a FSid ranging from 1.30 to 2.00 for construction damages can be used when gravel soil is used.

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