Stepped isothermal method to determine a combined reduction factor for creep and installation damage

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ABSTRACT: Since economic design, necessitated by limited resources and increased competition is a main target in the design process nowadays, manufacturers and designers seek to find method to increase their economic position without neglecting safety. This study links two important reduction factors in order to establish a methodology which enables manufacturers to combine the reduction factor for creep (RF_{CR}) and for installation damage (RF_{ID}) into a single value. This may result in a lower reduction factors than the conventional method, in which the multiplication of the two has been promulgated. There are however obstacles which have to be eliminated in doing this. The high costs involved in creep and creep rupture tests and the long time needed to perform those where important factors influencing the development. This study uses the newly developed Stepped Isothermal Method (SIM) for time-temperature superposition of creep data, which reduces this problem significantly. The material used was a woven polyester geogrid with PVC coating. A part of the material was exposed to installation damage in accordance to ISO 10722-1 and another part was exposed to a field simulation installation damage procedure according to “Watts and Brady”. SIM tests as well as conventional creep rupture tests where performed with virgin and with damaged specimens.

1 INTRODUCTION

The design approaches widely applied in soil reinforcement allow the use of reduction factors in order to take various different influences into account. Reduction factors reduce the numerical effort significantly, hence allow reasonable design procedures. The basic equation for determining the maximum allowable strength of a geogrid appears to be as follows:

$$F_{allow} = \frac{UTS}{RF_{CR} * RF_{IC} * RF_{CO} * RF_D} \qquad (1)$$

Where:
F_{allow} = Maximum allowable Strength
UTS = Ultimate Tensile Strength
RF_{CR} = Reduction Factor Creep
RF_{ID} = Reduction Factor Installation Damage
RF_{CD} = Reduction Factor Connection / Seams
RF_D = Reduction Factor Durability

The effect of simply multiplying the reduction factors in the denominator results basically in a of the creep rupture curve diminished by a factor, as shown in Figure 1.

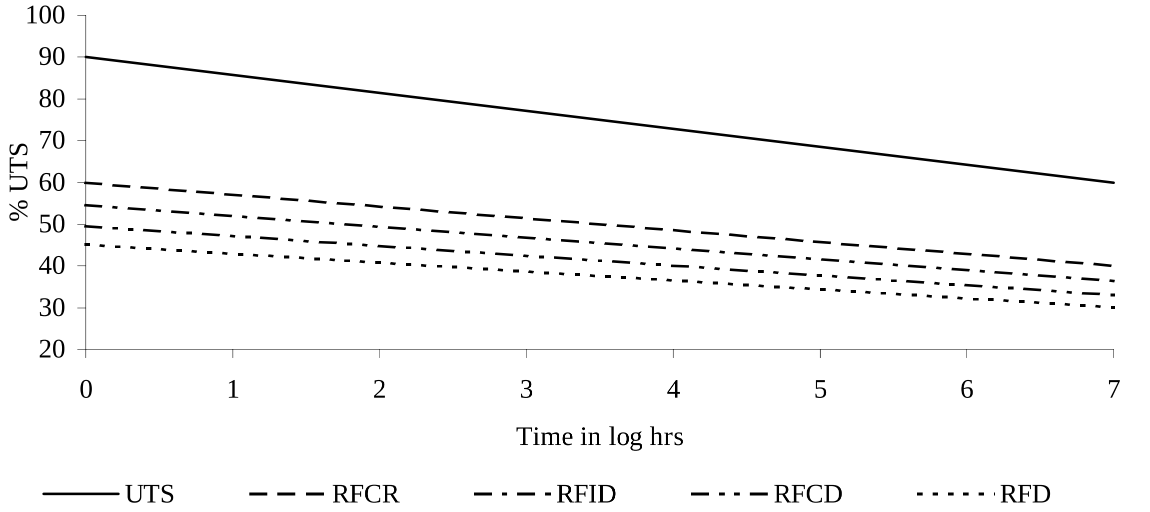


Figure 1: Effect of multiplying reduction factors

Allen et al (1996) concluded that “the multiplication of creep reduction and installation damage factors may be conservative and hence results in errors on the safe side for design”.

Since specimen to specimen variation is a variable in conventional creep and creep rupture tests, at least three (3) tests at every load level have to be performed, in order to obtain a statistically acceptable result.

Performing creep or creep rupture tests with damaged specimens has not been promulgated, because one can expect an even greater scatter in the obtained data due to implementing even more uncertainties in the testing. However, with the introduction of the Stepped Isothermal Method (SIM), the uncertainty of specimen to specimen variation has been reduced, because single specimen testing can be justified (Thornton et al, (1998A.)

Another major influence and cost factor in creep and creep rupture testing is time. Creep tests are a very time and hence cost intensive factor in product development and approval procedures.

If the manufacturer wants to sell his products and tests have not been performed, default reduction factors have to be applied. Thamm (1997) published them for creep and installation damage as given in Table 1 and 2:

Table 1: Minimum reduction factor creep and creep rupture

Geosynthetics consisting of	RFCR
Polyethylene or Polypropylene	≥ 5,0
Polyamide or Polyester	≥ 2,5

Table 2:Minimum reduction factors for installation damage

Soil consisting of round graining	RFID
Fine grain	≥ 1,5
Mixed and rough grain	≥ 2,0

These factors are far on the safe side, in order to insure a safe design. The reduction factors for the material tested here had been established conventionally and are shown in Table 3. This study tries to show how to link the two reduction factors in a very economic and efficient way, by using the Stepped Isothermal Method for developing creep and creep rupture curves with damaged specimen.

1.1 *Materials and Methods*

1.1.1 *Material*

The material investigated during this study was a medium weight PVC coated woven geogrid, made of high tenacity polyester yarns.

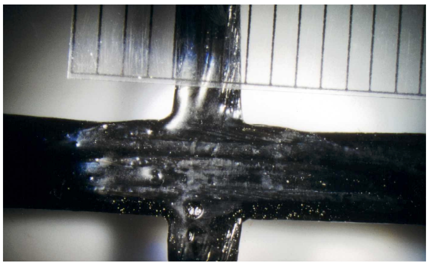
The basic properties appeared to be as follows:

Table 3: Properties of the material tested

Property	Unit	Value
Average weight per Unit Area	g/m²	352,0
RF_{ID}		1,10
RF_{CR}		1,52
Molecular weight	mmol/kg	30,000
Carboxyl End groups		< 30

The properties presented in Table 3 were published by the manufacturer.

Picture 1 shows an example of an undamaged specimen.



Picture 1: Undamaged specimen

1.2 *Specimen identification*

The specimens were not representatively taken over the roll width, but instead were defined in advance by region within the roll width of the sample. This was achieved by cutting the sample into seven (7) sequentially coupons of 1,2 m by 5 m. Each of those were then cut into 4 panels of 1,2 m by 1,2 m. The specimens allocated for each test were taken in sequence along machine direction, so that every rib has been tested in accordance to the same method, in order to minimize variation.

1.3 *Methods*

1.3.1 *Installation Damage*

1.3.1.1 Watts and Brady approach

The Watts and Brady approach is based on a test outline introduced by the Transport Research Laboratory (TRL) in its "Procedure for Installation Damage Test for BBA Assessment, TM028" in 1997 and is used as an "On Site Simulation". It shall reproduce on site conditions and activities and allows the exhumation of the test sample without applying any significant further damage. (Watts and Brady, 1994) It works in accordance with the requirements of the specifications for compacting backfill and it simulates effectively the soil compaction.

The procedure in accordance to "Watts & Brady" followed the following steps:

- 6mm thick steel plate were placed on a concrete floor
- lifting chains were attached to the eyes provided at one end of the plate
- one layer of backfill was placed into the bay and compacted as required
- specimen of 1,2m by 1,2m were placed onto the surface, directly over the area of each plate
- the second layer of backfill was placed on the specimen, insuring that the geogrids were not damaged or destroyed. The second layer was compacted to the required level.
- Samples were exhumed carefully by lifting the steel plates with an excavator.
- Specimen were visually inspected, photographed and prepared for further testing.

1.3.1.2 ISO 10722

The ISO Test for Installation Damage according to the ISO 10722-1 is an Index test which was developed in order to define a property of a material on the basis of reproducible laboratory tests. An extra procedure in addition to the Watts and Brady method was developed, because the latter is significantly more expensive due to high costs for machines, space and labor. The installation damage in accordance to ISO 10722-1 used the following test apparatus (Figure 2).

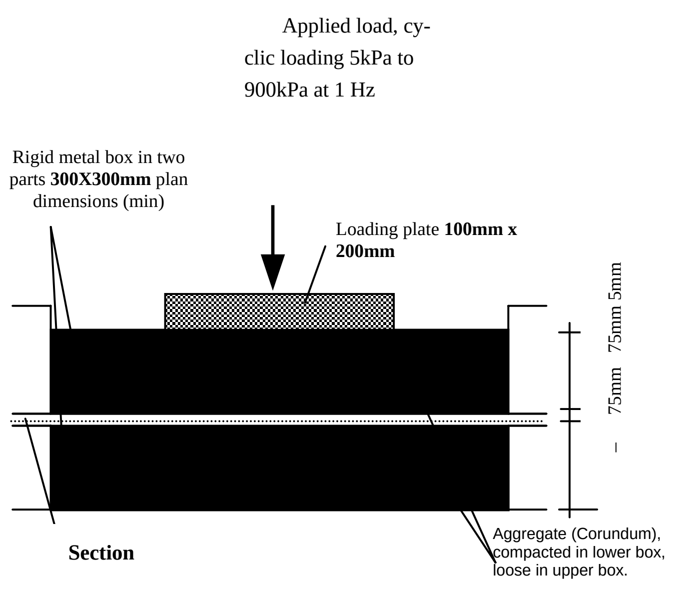


Figure 2: Test container Installation Damage

The tests followed this procedure:

- The lower part of the box was filled in two layers. Each layer was compacted with a 200 ± 2 kPa for 60 seconds.
- The specimen was placed onto the two layers of soil and covered with a layer of 150mm aggregate.
- The specimen was then aligned with the center of the container
- The loading plate was then centrally placed on the aggregate and specimen
- A load between 5 ± 5 kPa and 900 ± 10 kPa at a frequency of 1 Hz for 200 loading cycles was applied
- After applying the load, the specimen was removed carefully from the container.

Figure 3 shows an exemplary loading cycle for the test.

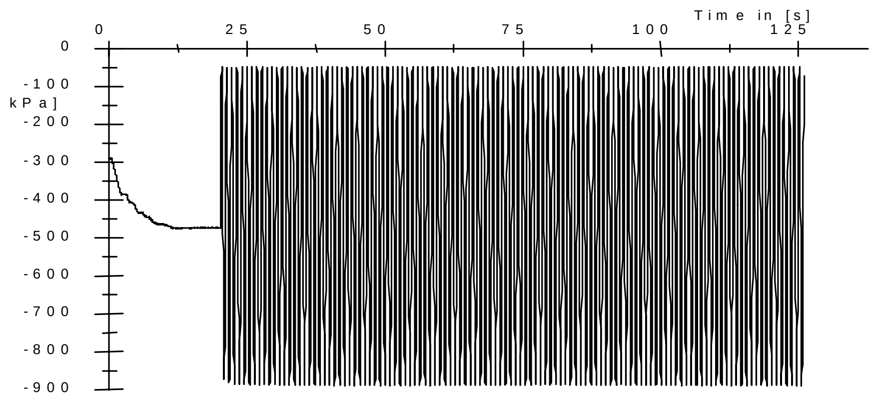


Figure 3: Load cycle ID test

Picture 2: Microscopic photograph of damaged specimen

Picture 2 shows a microscopic photograph of a damaged specimen. Obviously visible the damage done to the fibers, which result in a reduction of the tensile properties.

1.3.2 *Rapid loading Tensile Test (RLT)*

The Rapid Loading Tensile Tests were performed in accordance to ASTM 4595. A 5 rib wide specimen (approximately 10cm) was mounted into the grips and tested with a cross head speed of 10% strain per minute. The strain was measured with an Epsilon clip on extensometer, gage length 10,16cm.

1.3.3 *Conventional Creep Rupture Tests*

The conventional creep rupture tests where carried out by using

1. A universal tensile test machine for tests less then 100 hrs, and
2. A lever arm system as shown in Picture 4 for the remaining.

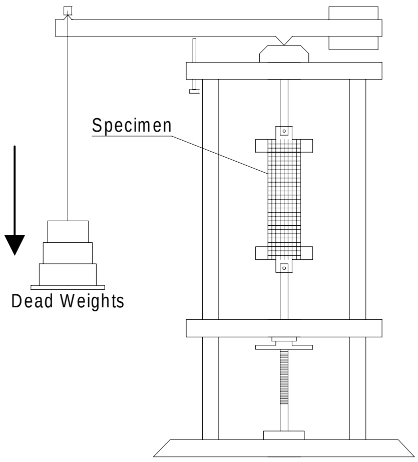


Figure 4: Lever arm system.

1.3.4 *Stepped Isothermal Method*

The conducted SIM tests were carried out in accordance to Thornton et al. (1998A).

The load is constant during the test, whereas the temperature takes the steps starting at 20°C and going up to 90°C in intervals of 10 000 seconds and steps of 14°C.
The reason why the developer chose steps of 14°Cis explained in Thornton (1998B). He states that one can chose them basically arbitrary, and developed an adequate temperature and time plan.

He states furthermore that for PET a procedure of 14°C steps every 10000 seconds seems to be the best. He tested in his study 3 different temperature steps in correlation with 3 different exposure times. He compared 1000 second tests with temperature steps of 7°C and 14°C with tests of 10000 seconds and 7, 14 and 28°C, and lastly tests of 100 000 seconds with steps of 14 and 28°C.
The result was that the procedure with 14°C and 10000 resulted in the most economical condition with good results, compared with data from conventional creep tests. That is the reason why he recommended 10.000 seconds and 14°C temperature steps as the standard protocol for PET.

The data analysis followed this procedure:

- Plot the creep strain and creep modulus as a function of linear time to identify the times for the temperature steps.
- Using the creep modulus as the parameter of interest, plot this parameter vs. Log time
- Rescale the times for the individual creep modulus segments by plotting them vs. the logarithm of the initial value of (t-t') where t' is adjusted to account for history. This will be achieved when the slope of the beginning of a new segment is exactly the same as the ending slope of the previous segment. This may require some iteration.
- Remove thermal expansion effects by vertical shifts
- Shift horizontally to achieve exact juxtaposition of the rescaled and vertically shifted individual creep modulus segments. This may as well require some iteration.

In total 22 SIM tests were performed. 12 of those were performed using damaged specimens. Picture 5 shows an example of an analyzed test.

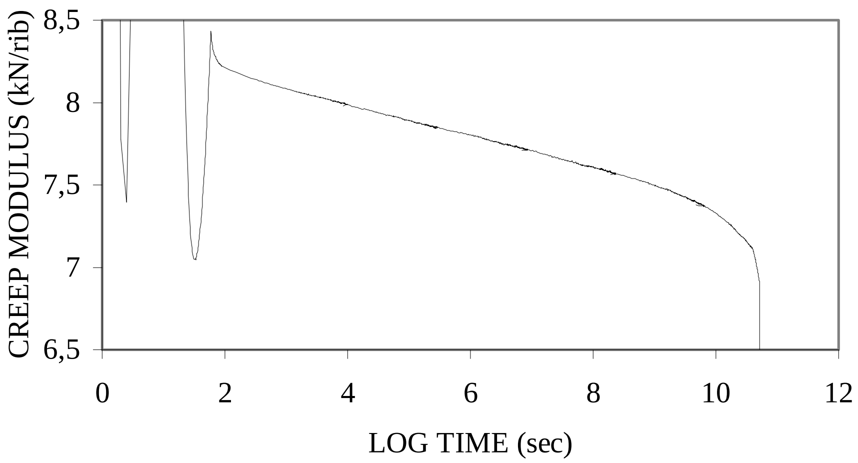


Figure 5: Analyzed SIM test

1.4 *Results*

The results obtained are shown in Table 6. Specimens number U13-U48 were undamaged, D13-D48 were damaged in accordance to “Watts & Brady” and D46-D78 were damaged in accordance to ISO 10722-1.

It is remarkably that the ISO procedure results in a much lower reduction factor for Installation Damage. This may be due to the relatively large aggregate used for the installation damage procedure.

1.4.1 *RLT – undamaged*

The baseline results are shown in Table 4.

Table 4: Baseline RLT results

Specimen No.	UTS kN/m	Strain %
U13	78,023	14,37986
U18	78,726	12,64268
U23	78,759	14,09706
U28	77,720	13,39837
U33	77,547	13,79193
U38	78,034	12,71218
U43	78,413	13,64908
U48	75,210	12,86032
Average	78,175	13,524
Std	0,474	0,658

1.4.2 *RLT – damaged Watts&Brady*

The RLT’s for specimen damaged in accordance to Watts&Brady are given in Table 5.

Table 5: RLT results after Watts&Brady installation damage

Specimen No.	Peak load kN/5ribs	Strain %
D13	45,8768	9,13
D18	62,0505	10,37
D23	55,4071	10,69
D28	56,1093	11,02
D33	46,9220	10,00
D38	43,9487	9,91
D43	63,0806	11,46
D48	60,3107	10,98
D11	47,5485	8,91
D39	45,6745	11,18
Average	52,6929	10,36
Std	7,4869	0,87

1.4.3 *RLT – damaged ISO 10722*

The RLT's with specimen damaged in accordance to ISO 10722 are given in table 6.

Table 6: RLT results after ISO installation damage

Specimen No.	UTS kN/m	Strain %
D46	64,236	11,319
D53	59,843	10,354
D58	63,395	10,893
D63	51,828	11,837
D68	59,755	10,123
D73	67,767	11,062
D78	58,234	10,398
Average	60,723	10,855
Std	5,101	0,608

1.4.4 *Reduction Factors Installation Damage*

The reduction factors for Installation damage based on RLT results are summarized in Table 7.

Table 7 : Comparison results obtained

Specimen ID	Strength KN/m	Strain %	RF_{ID}
U13 – U48	78,17	13,52	1,0
D13 – D48	52,69	10,36	1,48
D46 – D78	60,72	10,86	1,29

The obtained results show that the reduction factor for the Watts&Brady approach are much greater then the ones obtained with ISO 10722. This may be due to the fact that the aggregate used for the Watts&Brady damaging procedure was more aggressive.

1.4.5 *Creep rupture and SIM results*

The creep rupture and SIM results obtained are shown in Table 8.

Table 8: Creep rupture results (W = Watts&Brady damaged, I=ISO damaged, [1)]indicates conventional creep rupture tests

Spec. ID	Dam-age	Log hrs.	% UTS
U4	-	5,494	59,48
U5	-	97,01	59,79
U7	-	5,529	59,99
U9	-	4,575	60,67
A44	-	4,598	59,14
D6	W	3,000	48,01
D5	W	2,560	33,95
D15	W	4,290	47,99
D24	W	6,843	52,77
D26	W	5,769	51,79
D25	W	5,716	60,21
D27	W	4,644	56,73

D34	W	-1,669	57,97
D35	W	2,284	58,11
D19.1[1)]	W	-3,477	61,13
D19.2[1)]	W	2,413	60,14
D19.3[1)]	W	2,483	60,14
D19.4[1)]	W	2,963	61,16
D46[1)]	I	0,029	70,00
D76[1)]	I	0,022	70,00
D56[1)]	I	19,1	67,49
D75[1)]	I	0,024	70,00
D66[1)]	I	22,7	67,49
D71[1)]	I	0,033	70,00
D59[1)]	I	750	66,03
D47[1)]	I	750	66,03

These results along with a regression analysis are presented in Figure 6.

The test left of the dotted line and the marked test were conventional tests, the rest were SIM tests.

The graph shows a convergence, or intersection between the undamaged and the ISO damaged creep rupture regression curves. The intersection at about $10^{5,5}$ hours means that at about 36 years the retained strength of the damaged and the undamaged will not be distinguishable. Thus at that time the minimum reduction factor must be equal to the creep reduction factor. The large scatter in the data, especially of the Watts&Brady damaged specimens show that there are still great uncertainties involved.

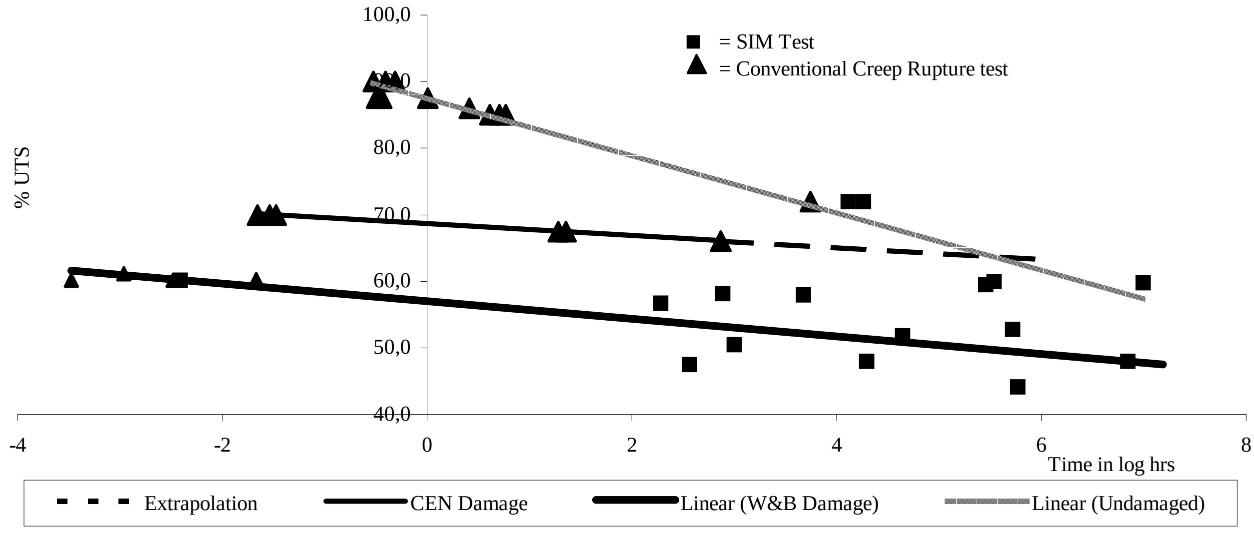


Figure 6: Regression analysis creep rupture for damaged and undamaged specimens

A comparison between the reduction factors is shown in Table 9.

Table 9:Comparison reduction factors

Test	Retained Strength	RF
$RLT_{undamaged}$	100,0	1,00
$RLT_{damaged,W\&B}$	67,6	1,48
$RLT_{damaged,ISO}$	77,5	1,29
$CR_{undamaged}$	61,2	1,62
$RLT_{damaged,W\&B,manufacturer}$	87,7	1,14
$CR_{undamaged,manufacturer}$	64,5	1,54

$$RF_{ID,W\&B} * RF_{CR,undamaged} = 1{,}48 * 1{,}62 = \quad 2{,}40$$

$$RF_{ID(W\&B),CR} = \frac{100}{-1{,}3194 * x + 57{,}009} = \frac{100}{-1{,}3194 * x + 57{,}009} = \quad 2{,}04$$

$$RF_{ID,ISO} * RF_{CR,undamaged} = 1{,}29 * 1{,}62 = \quad 2{,}09$$

$$RF_{ID(ISO),CR} = \frac{100}{-0{,}8907 * x + 68{,}622} = \frac{100}{-0{,}8907 * 6 + 68{,}622} = \quad 1{,}58$$

The actually gained difference for the approach shown for the ISO damaging procedure is 0,51 and for the Watts and Brady approach is 0,36. Since the creep reduction factor is 1,62, this must be the minimum reduction factor.

Another important point to make is, that the utilization of the specimens for each test have to be designated prior to the installation damage procedure.

The obtained results show, that improvements are possible, however, the need for more data is obvious, since the scatter in the data makes the test uncertain. Other materials, consisting of other raw materials and other ways of manufacturing need to be tested as well.

REFERENCES

Allen, T. M. and Bathurst, R. J. 1996. Combined allowable strength reduction factor for geosynthetics creep and installation damage: *Proceedings Geosynthetics International ’96 Conference in Singapore*

ASTM D2990 –95 1995. Standard Test Method for Tensile, Compressice and Flexural Creep and Creep Rupture of plastics *ASTM US*

DIN EN ISO 13431 1998. Geotextilien und geotextilverwante Produkte – Bestimmung des Zugkriech- und des Zeitstandverhaltens

DIN EN ISO 10319 1996. Geotextilien, Zugversuch am Breiten Streifen

Thamm, B. 1997. Berechnung und Dimensionierung von Erdkörpern mit Bewehrungseinlagen aus Geokunststoffen. *Geotechnik Heft 20*

Thornton. J. S., Allen, S. R. and Thomas, R. W. 1998A. Approaches for the prediction of Long Term viscoelastic properties of Geosynthetics from short term tests. *Proceedings of Geosynthetics ’98 Conference in Atlanta*

Thornton. J. S., Allen, S. R. and Thomas, R. W. and Sandri, D 1998B._The Stepped Isothermal Method for Time Temperature Superposition and Its Application to Creep Data on Polyester Yarn. *Proceedings of Geosynthetics ’98 Conference in Atlanta*

Thornton. J. S., Paulson, J. N. and Sandri, D 1998C. Conventional and Stepped Isothermal Methods for Characterizing Long Term Creep Strength of Polyester Geogrids. *Proceedings of Geosynthetics '98 Conference in Atlanta*

Transport Research Laboratory 1997. Procedure for Installation Damage Test for BBA Assessments

Watts, G. R. A. & Brady, K. C. 1994. Geosynthetics: Installation Damage and the Measurement of Tensile Strength; *Proceedings 5th International Conference on Geotextiles and Related Products, Singapore*