The long term performance of polymeric reinforced walls under static and seismic conditions

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ABSTRACT: Data is presented that shows that polyester based reinforcement from two reinforced soil walls, at Elmadag Turkey and at the Transport Research Laboratory (TRL) UK, have lost no strength and have the same load – strain response as the original materials after 22 and 37 years in service respectively. Scanning electron microscope images showed that no degradation on the surface of the polyester fibres had occurred and chemical testing showed that the number avearge molecular weight and carboxyl end group count were unchanged from that measured in the original fibres. The results presented in this paper extend the data on the insitu preformance of poylester based geosynthetics over extended periods of time. Samples exhumed from the TRL wall, at regular intervals, over the past 28 years have shown no change in the load – strain responce of the geosynthetic reinfrocement. The samples exhumed from the Elmadag wall in Turkey are the second set of samples exhumed and tested from a reinforced soil structure that experienced a secimic event. No change in the load – strain relationship, apperance or chemical properties of the polyester fibres indicates that the long term performce of polyester based geosynthetics may not be affected by secimic events.

Keywords: Soil reinforcement, design life, polyester, exhumed samples, testing

1 INTRODUCTION

The first modern soil reinforced structures were built during the late 1960's and early 1970's. In the 1970's polymeric reinforcement elements appeared on the market and these now account for the majority of reinforcement materials used in this technique. Polymeric materials are visco-elastic and require careful evaluation to determine appropriate long-term stress-strain characteristics.

The polyester used in the reinforcing geosynthetics of the 1970's was initially developed by Imperial Chemical Industries, ICI, for use in the rubber cord, car seat belts and ropes industries. This material was ideal for soil reinforcement applications due to its high tensile strength and modulus properties. The factors that were unknown at the time were the long-term durability characteristics of the material for use in soil structures, which typically have a design life of 100 – 120 years.

The long-term performance of polymeric reinforcement is now reasonably well understood (ISO TR 20432, 2007). The effects of installation damage, environmental durability and creep are determined through laboratory and field testing, typically examining each effect independently and under idealised conditions. The predicted reduction in the reinforcement strength can be quantified through partial material factors / reduction factors that are applied to the short-term strength of the reinforcement (ISO TR 20432, 2007). While this approach works well in practice, it is useful to validate the process through the evaluation of exhumed reinforcement material that has been in service for an extended period of time.

This paper presents data on the performance of polymeric reinforcement exhumed from two walls after 22 and 37 years of service respectively. Samples were exhumed from a wall at Elmadag, Turkey, in 2009 following 22 years of service. This is the second wall to have samples exhumed following a seismic event, the first being the Kınali – Sakarya motorway wall reported by Naughton et al. (2008). The second wall examined in this study was the TRL wall, UK, where sample have been exhumed at regular intervals over the past 37 years. The data presented in this paper is for samples exhumed in 2014.

The polymeric reinforced used in the construction of both walls reported in this paper came from a family of reinforcement geosynthetics consisting of high tenacity polyester encased in a polyethylene sheath. The manufacturing process allows the production of both rectangular and circular sections. The circular sections are used as synthetic ropes in a variety of civil engineering applications. The rectangular sections are used in reinforced wall applications or combined to form bi- and uni-directional geosynthetics for the reinforcement of walls, steep slopes and the construction of embankments over soft ground, over piles and over areas prone to subsidence. The strength of the uni-directional geogrid, called ParaLink, range from 200 kN/m to 1500 kN/m, while the straps used in reinforced soil walls, called ParaWeb, range in strength from 30 to 100 kN per strap.

Naughton et al (2005) provided an extensive discussion on the initial and long-term characteristics of this family of geosynthetics (grid and linear reinforcing elements used in steep slopes, reinforced soil walls and basal reinforcement applications) of which the reinforcement elements in this paper are members.

2 BACKGROUND TO THE TRANSPORT RESEARCH LABORATORY WALL

In 1977 a full scale, 6 m high, reinforced soil trial wall was constructed at the Transport and Roads Research Laboratory (now called the Transport Research Laboratory, TRL) Berkshire, United Kingdom (UK). The primary objective of the trial was to optimise the use of the reinforcing elements in terms of length, spacing and orientation and to investigate the possible use of reinforcements other than those in common use at that time.

The reinforcing elements included in the wall consisted of fibre reinforced plastic, stainless steel, galvanised mild steel, aluminum coated mild steel, plastic coated mild steel, prestressed concrete planks and polyester filaments encased in polyethylene, which is the topic of this paper. Each reinforcement type was allocated to a particular section of the wall. Three types of fill were employed. The first layer consisted of sandy clay having a relatively low clay content. The second layer was constructed with free draining granular material and the final layer was silty clay with a higher clay content than that selected for the first layer. The layout of the wall is shown schematically in Figure 1.

The facing units used with the polymeric reinforcement were reinforced concrete interlocking units with typical dimensions of 450 mm x 450 mm x 80 mm thickness. The units were shaped such that they interlocked with adjacent units using cast in dowels and sockets. A photograph of the polymeric section taken in March 2005, 28 years after construction, is shown in Figure 2(a).

The structure was instrumented with piezometers, pressure cells, settlement plates, thermocouples and locating studs mounted on the facing units. In addition, strain gauges, of the electrical resistance type were mounted in pairs on either side of the reinforcing straps to measure the tension in the reinforcement elements, Figure 2(b). For details on the measurement values reference should be made to Boden et al. (1977) and Brady et al. (1995).

2.1 *Construction details used in the TRL wall*

The TRL wall is an early example of a reinforced soil wall constructed using polymeric reinforcement and some aspects of construction are interesting from an historic perspective. Firstly, the facing panels were significantly smaller, at 450mm x 450mm, Figure 2(a), than the typical 1.5m x 1.5m panels commonly used in this type of construction today. Secondly, the connections between the reinforcement and the facing panel were manufactured from stainless steel, Figure 3(a), and were significantly different in size and structure to their modern day equivalent. Finally, the layout of the reinforcement in today's world seems wasteful. The polymeric straps were installed as individual straps which were returned back on themselves, Figure 3(b). This is in contrast to the now customary and more efficient zig-zag pattern commonly used with polymeric reinforcement.

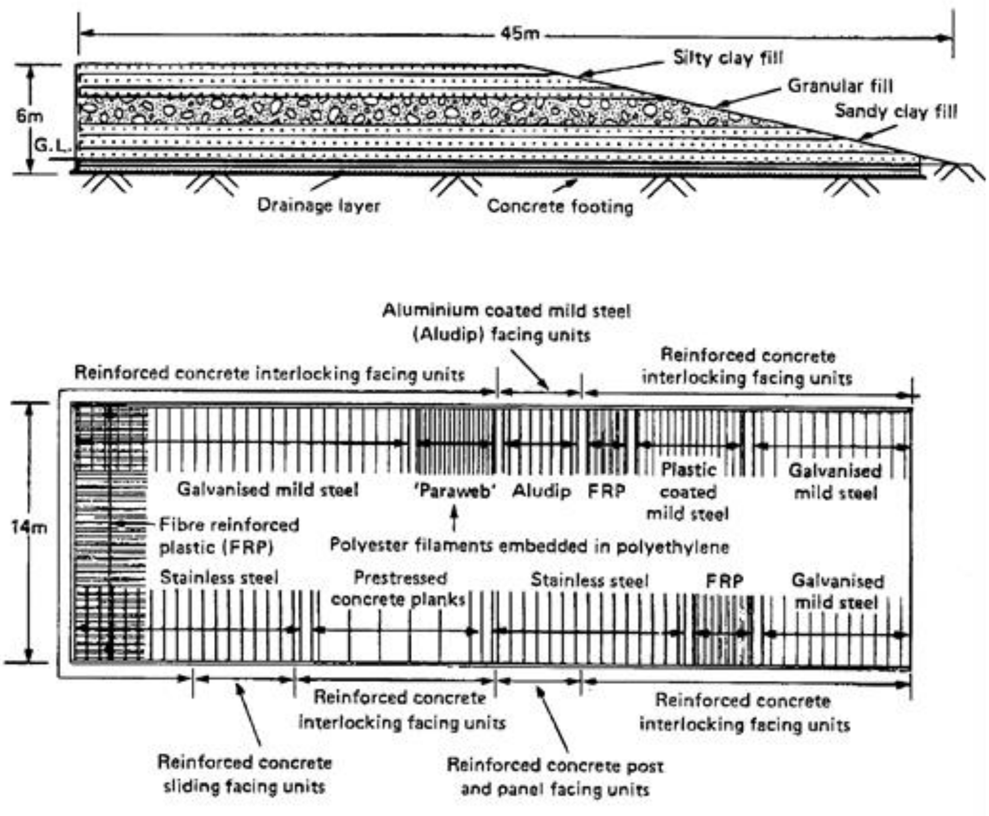


Figure 1: Schematic of the TRL wall

2.2 *Exhumation of samples from the TRL wall*

Samples of polymeric reinforcement have been exhumed from the wall by the TRL in 1984 and 1990 (Brady et al, 1995) and by Linear Composites in 1994 and 2005 (Naughton et al, 2005 & Kempton et al, 2008). The most recent samples were exhumed in 2014 by Linear Composites, following 37 year of service, and are the subject of this paper. These are likely to be the last samples retrieved as the site where the wall is located is scheduled for redevelopment.

For practical reasons the exhumed samples came from the upper layers of the wall, at depths of approximately 1 m. The backfill soil in this region consisted of silty clay, with a relatively high clay content, Figure 2(b). It can be reasonably assumed that this soil layer was partially saturated and would have a degree of saturation in the range 40 – 70%.

All the exhumed samples were visually inspected after exhumation. Naughton et al. (2005) reported that the previously exhumed samples were generally in good condition although some physical damage was evident, which was attributed to the excavation process. Samples retrieved in 1984, 1990 and 1994 exhibited cracking of the polyethylene sheath on the reinforcement at the location where it wrapped around the pin attachment to the concrete facing panel. Samples exhumed in 2005 and 2014 showed no evidence of this type of cracking.

(a) (b)

Figure 2: (a) External view of section containing polymeric reinforcement and (b) Exhumed sample from 2014 showing original strain gauge used during TRL monitoring programme

(a) (b)

Figure 3: (a) Connection between polymeric reinforcement and concrete facing panel and (b) strap installation

3 BACKGROUND TO THE ELMADAG WALL

The reinforced soil wall at Elmadag, Figure 4(a), was constructed between 1986 and 1987 and was both the first reinforced soil wall in Turkey and the first constructed using polymeric reinforcement. The wall is located at the village of Elmadag, approximately 30km east of Ankara on the highway to Samsun. The wall consisted of T shaped panels, nominally 2.0m wide x 1.6m high, with typically four reinforcement connection points per panel. The polymeric reinforcement had a short-term design strength of 50kN (BBA, 1982). The polymeric reinforcement was connected to the panel through a metal connection consisting of two loops and a toggle, Figure 4(b). The metal loops were cast into the facing panel during manufacture. The reinforcement was also installed using the now customary zig-zag pattern. The total area of the facing panels was approximately 4400m^2, with the wall varying in height to a maximum of 7m. The fill material used in the construction of the wall was river gravel.

The Turkish Disaster and Emergency Management Directorate have classified the area in which the wall is located as a third degree earthquake zone, where a seismic acceleration of 0.2 should be used in design. Since construction the wall has experienced and survived, without any damage, several earthquakes. In 2004 a 3.8 magnitude earthquake with an epicenter close to Elmadag resulted in no damage to the wall.

3.1 *Exhumation of sample from the Elmadag wall*

Exhumation of samples from the Elmadag wall occurred in 2009, following approximately 22 year of service in the wall. The samples were retrieved from the lower height part of the structure, with the samples located close to the surface. A mechanical excavator was used to remove fill, with hand tools used in close proximity to the samples, Figure 4(b).


(a) (b)

Figure 4: (a) External view of Elmadag wall and (b) exhumation of samples

4 EVALUATION OF EXHUMED SAMPLES

The performance of the samples exhumed from both the TRL and the Elmadag walls was evaluated visually, to determine any damage on the surface, and using scanning electron microscope (SEM) images to determine any damage to the fibres. Mechanical testing to determine the strength and load – strain response was also undertaken. Finally, chemical testing to determine the carboxyl end group count and number average molecular weight were conducted.

Tensile testing of the exhumed samples, to a modified ISO EN 10319 (2015) test procedure, was used to determine the retained strength of the exhumed reinforcement. This test procedure gave a direct measurement of the strength of the material and allowed a direct comparison between the load–strain relationship of the materials at the time of manufacture and with previously exhumed samples. Exhumed samples were cleaned to remove any soil residue and thoroughly dried before testing.

A scanning electron microscope technique was selected to examine the surface profile of the polyester fibres and to assess if any damage or degradation on the surface of the fibre due to hydrolysis was visible. The SEM technique was selected as it would identify surface pitting and holes which would indicate outer hydrolysis of the polyester. This technique was chosen alongside chemical analysis as it is often difficult to prepare recovered fibres for chemical testing; the fibres can become contaminated with soil and polyethylene from the outer sheath of the reinforcing elements. Fibres for testing were taken directly from the recovered samples and placed in the SEM. No cleaning or other preparation technique was applied to the sample.

The carboxyl end group count and number average molecular weight of both the original fibre and samples of fibre taken from the exhumed samples were tested in accordance with GRI GG7 and GRI GG8 respectively.

4.1 *Visual inspection of the samples*

Exhumed samples from both sites were examined visually to quantify any damage to the surface of the reinforcement. No significant damage was noted, Figure 5(a). Some minor damage, with pull through of small amounts of fibre, was observed, Figure 5(b), but these were very isolated. It was not possible to attribute this minor damage to original installation, in service use or to the exhumation process.


(a) (b)

Figure 5: Exhumed samples from the TRL wall showing (a) minor damage (b) some pull through of fibres

4.2 *Tensile strength and load–strain relationship of sample exhumed from TRL wall*

Seventeen tensile strength tests were performance on the samples of polymeric reinforcement exhumed from the TRL wall in 2014. Table 1 presents a summary of the maximum tensile strength of the reinforcement and the corresponding strain at maximum load. Figure 6 presents the load – strain relationship of the exhumed samples, together with the mean load – strain relationship based on all the samples tested. In total, four out of the seventeen samples tested had a tensile strength less than the original short-term design strength of 30kN.

4.3 *Tensile strength and load–strain relationship of sample exhumed from the Elmadag wall*

The length of reinforcement retrieved from the Elmadag wall facilitated four tensile tests. Table 1 presents a summary of the tensile test data, while Figure 7 presents the measured load – strain relationships for the individual samples and also the mean load – strain relationship for these samples. The measured strength of all the exhumed samples were higher than the initial short-term design strength of 50kN.

Table 1. Retained strength and corresponding strain of polymeric reinforcement exhumed from the TRL and Elmadag walls

	TRL wall		Elmadag Wall	
	Maximum tensile strength (kN)	Strain at maximum tensile strength (%)	Maximum tensile strength (kN)	Strain at maximum tensile strength (%)
Mean value	32.2	13.3	57.5	14.4
Standard Deviation	1.97	1.09	3.92	0.64
Range of values	28.6 – 34.4	11.3 – 15.7	51.6 – 59.7	13.9 – 15.3

4.4 *SEM images of fibres from the TRL and Elmadag walls*

Three types of fibre were examined in the SEM; the first were samples of the original polyester fibre, Figure 8(a) and (b) used in the manufacture of the reinforcement elements for the TRL wall in 1977, the second were fibres from the exhumed reinforcement from the TRL wall, Figure 8(c) and (d) and the third were fibres from the exhumed reinforcement from the Elmadag wall, Figure 8(e) and (f). The recovered samples from the TRL wall at a magnification of 1000x do show some contamination on the surface with flecks of unknown material clearly visible in the images, Figure 8(c). The recovered samples from both the TRL, at a magnification of 4000x, and the Elmadag walls, at a magnification of 2400x, show no evidence of pitting or surface damage, resulting from outer hydrolysis, Figure 8(d) and (f) respectively.

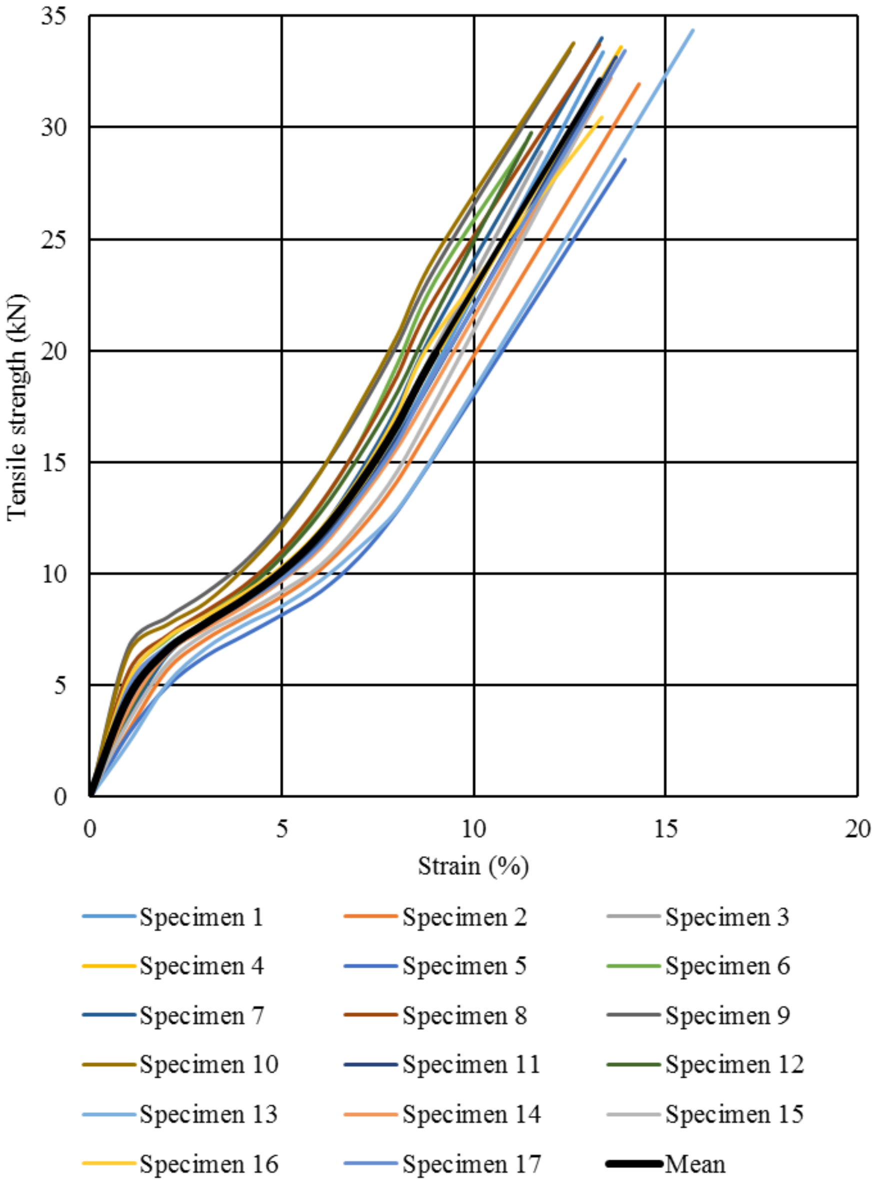


Figure 6: Stress – strain relationship of exhumed samples from the TRL wall

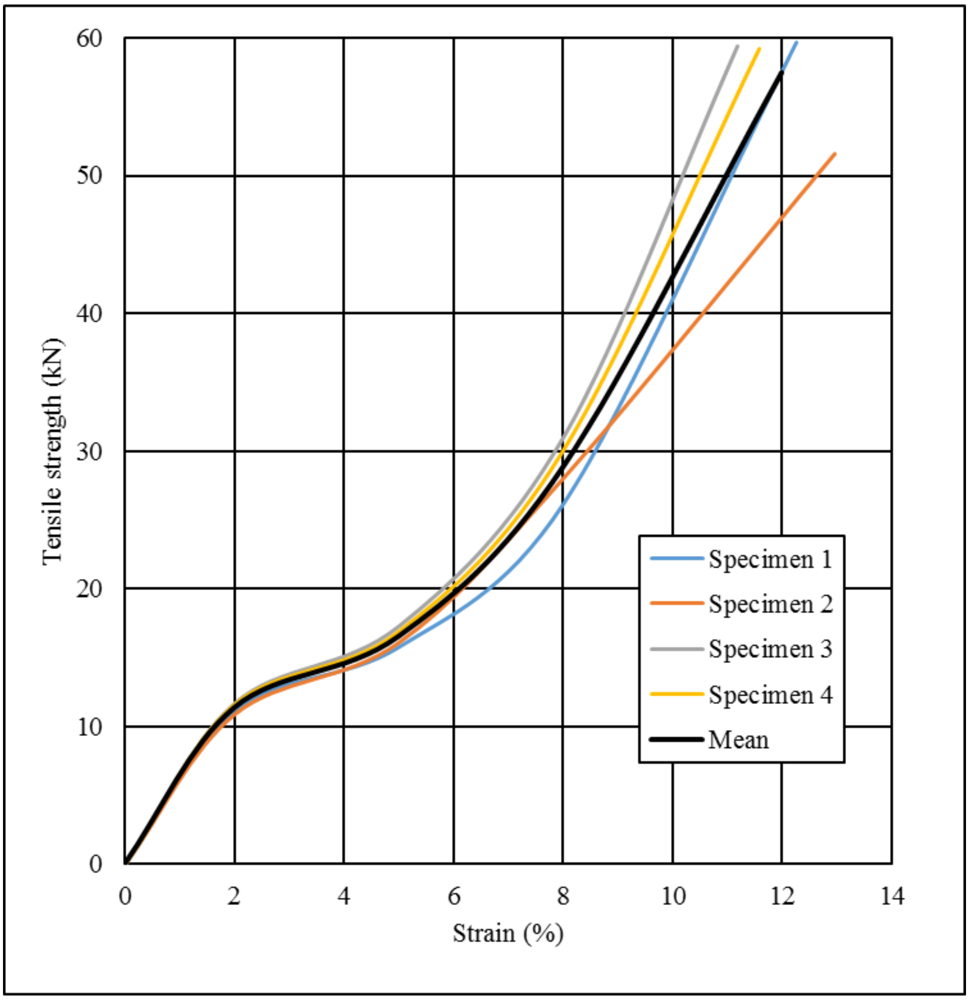


Figure 7: Stress – strain relations for exhumed samples from Elmadag wall

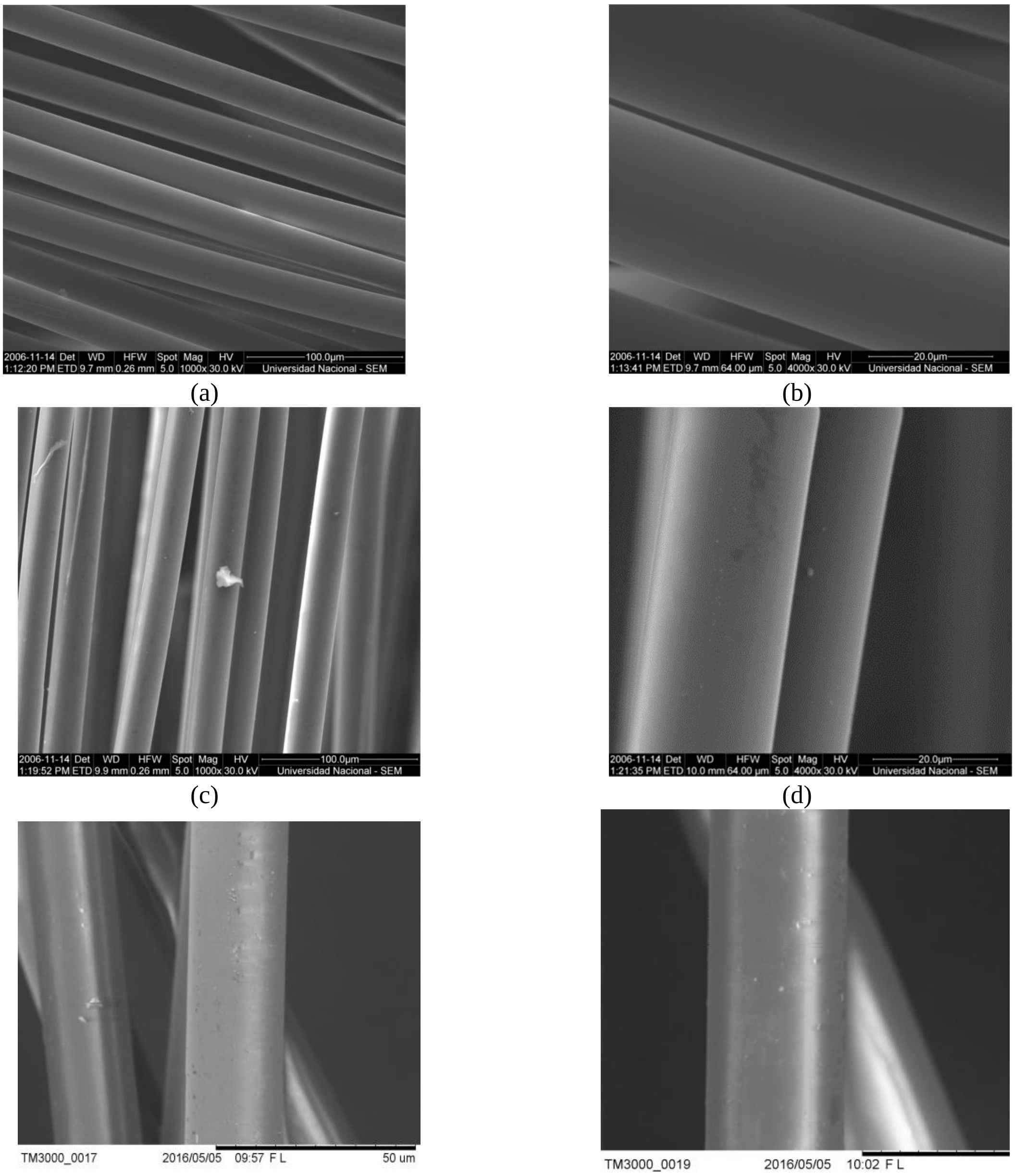
4.5 *Chemical testing of exhumed fibres*

The carboxyl end group count and number average molecular weight of the virgin sample fibre used in the manufacture of the reinforcement and samples of fibre taken from the exhumed reinforcement from both the TRL (values from samples exhumed in 2005 and reported in Naughton et al, 2009) and Elmadag walls were determined in accordance with GRI GG7 and GRI GG8 respectively. The results of the testing are presented in Table 2. No significant change in either parameter was observed.

Table 2. Number average molecular weight and carboxyl end group count for the virgin polyester and fibre taken from the reinforcement exhumed from the TRL and Elmadag walls

	Virgin fibre	Fibre from TRL wall*	Fibre from Elmadag wall
Number average molecular weight	33,518	33,570	36,344
Carboxyl group	39.5	35.9	28.5

* Values from samples exhumed in 2005 and reported in Naughton et al, 2009



(a) (b) (c) (d) (e) (f)

Figure 8: SEM images of (a) and (b) original virgin polyester used in the manufacture of the reinforcement used in the TRL wall at 1000 and 4000 magnifications respectively, (c) and (d) fibre from the exhumed TRL samples at 1000 and 4000 magnifications respectively and (e) and (f) fibres from the exhumed sample from Elmadag wall at 1800 and 2400 magnifications respectively

5 PERFORMANCE OF REINFORCEMENT SINCE CONSTRUCTION OF WALLS

5.1 *Strength and load – strain response of the reinforcement*

Samples of reinforcement have been exhumed from the TRL wall in 1984, 1990, 1994, 2005 and 2014 and the load – strain response determined. The load – strain data for the original reinforcement was also available. Figure 9 presents a comparison of mean load – strain relations for both the original material and the exhumed samples over the years. No reduction in maximum tensile strength or change in the load – strain response of the material has occurred since construction. Table 3 presents a comparison of measured strength parameters for the

TRL wall, indicating that the variation in the strength parameters of the exhumed samples has been consistent since the first samples were exhumed in 1984.

A comparison of the load – strain response for the reinforcement from the Elmadag wall is presented in Figure 10, and shows no reduction in the maximum tensile strength or change in the load – strain relationship between the original material and that exhumed after 22 year of service.

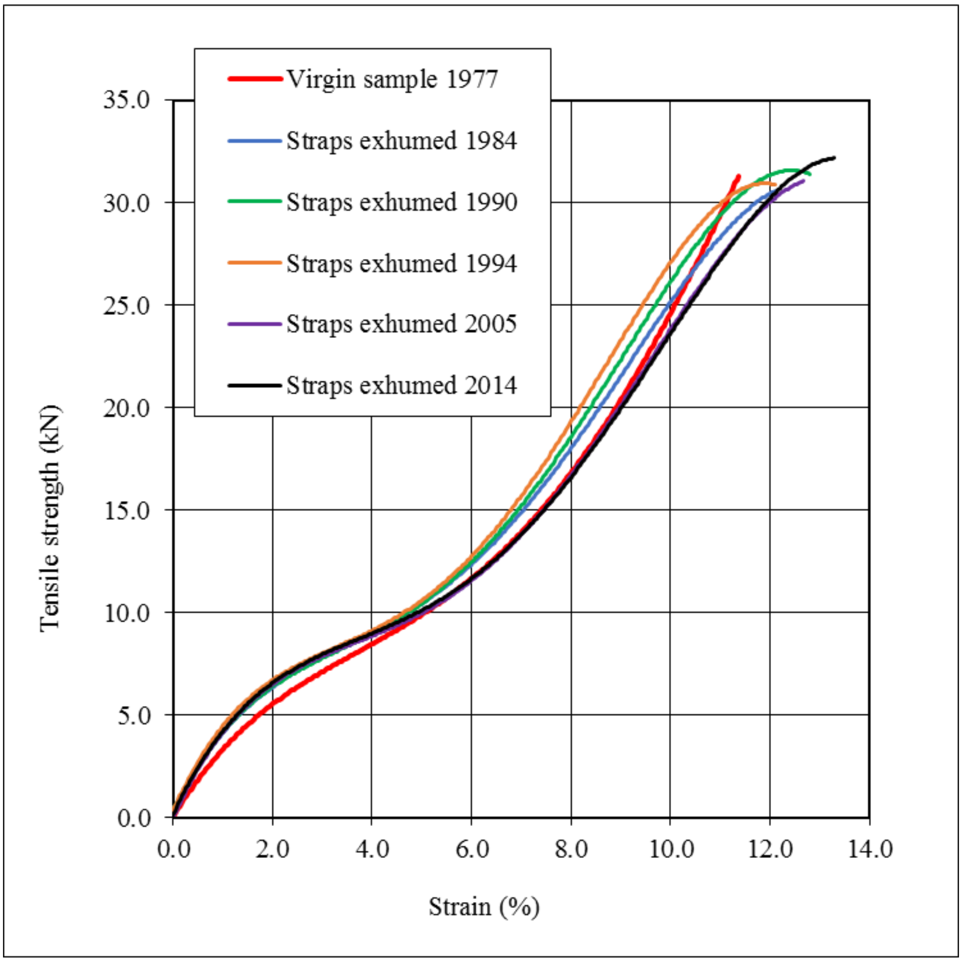


Figure 9: Load – strain relationship for original and exhumed samples from the TRL wall

Table 3. Comparison of measured values of samples exhumed from the TRL wall between 1984 – 2014

Year samples exhumed	No of specimens tested	Mean tensile strength (and range)		Mean elongation (and range)	
		Value (kN)	Relative to initial strength (%)	Value (%)	Relative to initial elongation (%)
Initial sample	-	31.3 (-)	100.0	11.40 (-)	100.0
1984	8	30.6 (27.5-32.5)	97.8	12.1 (10.5-13.0)	106.1
1990	9	31.4 (28.9-32.4)	100.3	12.8 (11.8-13.7)	112.3
1994	11	30.9 (27.5-32.0)	98.7	12.1 (10.5-12.9)	106.1
2005	5	31.0 (29.3-33.0)	99.2	12.7 (11.9-13.9)	111.2
2014	17	32.2 (28.6-34.4	102.9	13.3 (11.3-15.7)	116.7

6 DISCUSSION AND SIGNIFICANCE OF RESULTS

Polyester based reinforcing elements retrieved from structures in Turkey and the UK, which were in service for 22 and 37 years respectively, showed no reduction in strength or change in load – strain response. SEM images of the polyester fibres showed that no physical changes or degradation had occurred and the retrieved samples had the same profile and cross section as the original virgin polyester fibre. Chemical testing also showed no reduction in the pertinent parameters.

The determination of the long – term strength of polymeric reinforcement is dependent on an understanding of environmental durability and creep of the load carrying fibres in the reinforcement. Installation damage is also a consideration. However, installation damage is dependent on the properties of the protective coating around the fibres, in this case polyethylene, and the bundling of the fibres in the reinforcement and is not consider time dependent (ISO TR 20432, 2007).

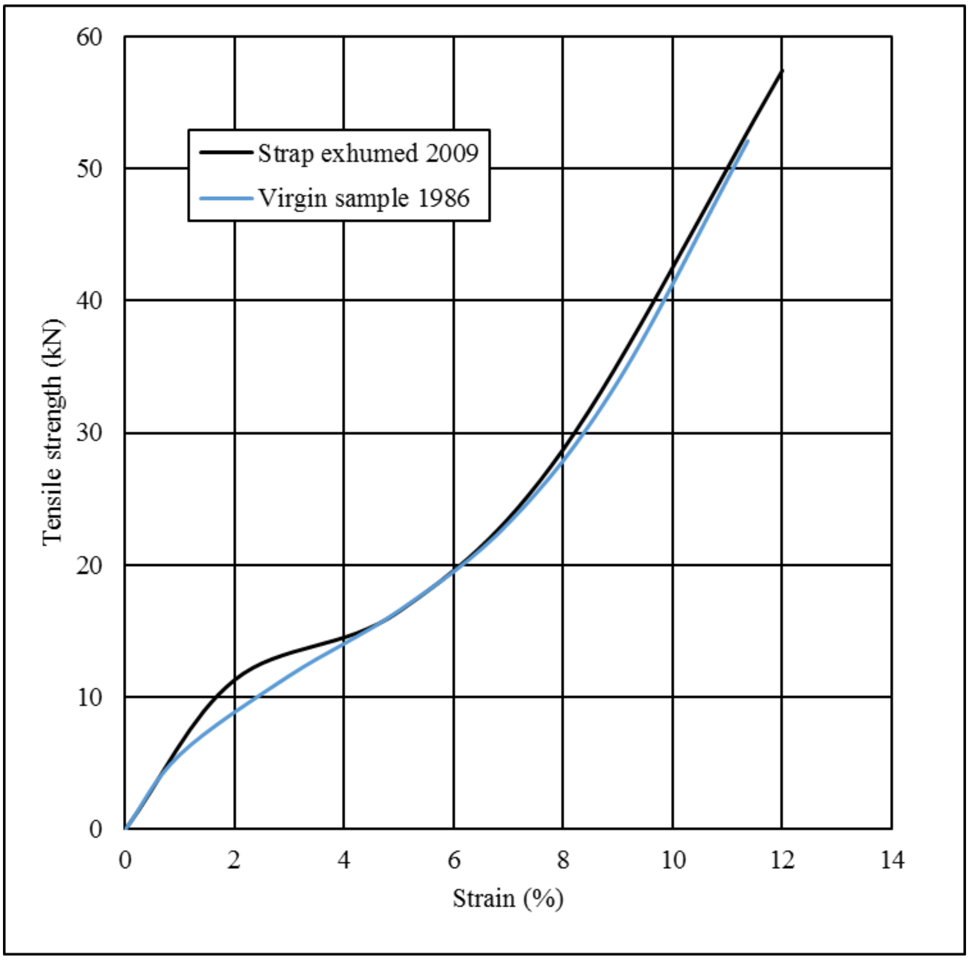


Figure 10: Load – strain relationship for original and exhumed sample from the Elmadag wall

Naughton et al (2009) assessed the effects of temperature and environmental degradation on the behavior of reinforcement exhumed from the TRL wall (up to 2005) and from another wall in Turkey (the Kinali – Sakarya Motorway). They concluded, based on the test data, that hydrolysis, which is the primary mode of environmental durability degradation in polyester, was not a concern when designing reinforced soil structures in unsaturated conditions. Using a method proposed by Burgoyne and Merii (2007) and the data from the TRL testing they predicted a lifespan of between 1600 and 4000 years for polyester at a design temperature of 20^0C and between 140 and 320 years for polyester at a design temperature of 40^0C. The typical design life a soil reinforced structure is between 100 and 120 years.

ISO TR 20432 (2007) stated that the strength of polyester fibres does not reduce until very close to failure of the fibres. This was confirmed by Greenwood (1997) and Orsat et al. (1998) through testing on polyester reinforcement. Naughton & Kempton (2006) developed a life time prediction model, based on the data generated by Greenwood (1997) and Orsat et al. (1998), that showed the time to failure of polyester based geosynthetics, taking into account both hydrolysis and creep, loaded to 65% of its capacity and with a design temperature of 30^0C would fail in approximately 500 years, considerably in excess of the typical design life of 100 – 120 years.

7 CONCLUSIONS

Data is presented that shows that polyester based reinforcement from two reinforced soil walls have lost no strength and have the same load – strain response as the original materials after 22 and 37 years in service respectively. SEM images showed that no degradation on the surface of the polyester fibres has occurred and chemical testing showed that the number avearge molecular weight and carboxyl end group count were unchanged from that measured in the original fibres.

The results presented in this paper extend the data on the long-term preformance of exhumed polyester based geosynthetics from reinforced soil structures.

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