THE LONG TERM PERFORMANCE OF POLYMERIC REINFORCED WALLS UNDER STATIC AND SEISMIC CONDITIONS

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Abstract: High tenacity polyester encased in a durable polyethylene sheath (Paraweb), was the first polymeric soil reinforcement material. This geosynthetic was used in reinforced wall applications in the mid-late 1970's and in the intervening 30 years has been used extensively world wide in a large variety of climates in this application.

This paper describes the design and construction of polymeric reinforced walls. Several case histories are presented where samples of polymeric strip reinforcement have been exhumed after 20 and 30 years of service. In one case history samples are exhumed from a 20-year-old wall that experienced a magnitude MW 7.4 earthquake in 1999. No reduction in strength was measured in the exhumed samples from the different case histories. This confirms data already presented by Naughton et al. (2005) and Greenwood (1997) that high tenacity polyester based reinforcement has significant residual strength.

The case history of the walls subjected to the earthquake loadings also presents information on the survivability of 18 m high polymeric and much lower metallic reinforcement walls that were constructed in close vicinity to each other. The polymeric reinforced walls were found to have survived the earthquake well with no distress evident, while significant damage was caused to the metallic reinforced walls. Information on the dynamic seismic design of the walls is presented. Recommendations are also presented on how residual strength should be incorporated into traditional design codes of practice for polymeric reinforced walls.

Keywords: earthquake, field performance, Newmark analysis, pseudo-static method, reinforced soil wall, seismic behaviour

INTRODUCTION

During the 1970’s interest was developing in the use of polymeric materials for civil engineering applications. While geotextiles began to be used increasingly from the early part of the decade the focus quickly expanded to the possible use of various polymeric strip materials for soil reinforcing techniques. This was partly driven by manufacturers seeking further uses for the new materials they were developing but also by the UK Government which took an early interest in reinforced soil wall techniques and the prospect of extending the use of such methods to situations in which poor quality fills, that are aggressive to steel reinforcements, could be used. Early attempts to use stainless steels in such environments had not been successful for reasons of corrosion and were generally abandoned.

The biggest impetus to this development came in 1977 by the construction of a large trial structure at the Transport and Road Research Laboratory (TRRL) facility at Crowthorne as described by Boden et al (1977). This structure used a number of materials of which the polymeric strip which is the subject of this paper was one (Figure 1). These materials continue to be exhumed for test from the structure to this time and, most recently, the results of these tests have been reported by Naughton et al (2005). The structure also used a range of fill types as it was recognised at the time that the UK had only limited availability of good quality fills and that the use of polymeric reinforcement materials also provided an opportunity to use alternative fills because of the absence of the kind of corrosion concerns that had always been present when considering the use of metallic reinforcing elements.

The experience gained from the construction and monitoring of this wall lead to the publication of the UK’s first design document for reinforced soil walls, BE3/78. It also provided information for the first BBA Certificate for walls using polymeric materials in 1978, No.78/601. The following decade produced many innovative uses of the technique in the UK such as the Harbour Wall in Jersey reported by Kempton et al (1985) and John (1983) and the Carmarthen Bridge Abutments reported by Brady (1987) and Brady et al (1995). Subsequently more adventurous uses of marginal fills began to be attempted and one such was the 14m high wall using pulverised fly ash fill as part of the Newcastle Western Bypass in 1988. Areas in the world where soil conditions also favoured polymeric materials, such as the Middle East and Far East also saw rapid developments in the use of the method. One such was Turkey (Özçelik, 2006) where natural soils often have a high fines content. This paper reports the first of these, the Kinali-Sakarya Motorway in Istanbul, particularly because of the design approach adopted for, and the performance in, severe seismic conditions. Another interesting outcome was the performance of walls on the Fahaheel Expressway in Kuwait which were built in 1982-84 and some of which were hit by missiles during the Gulf War in 1991 (Figure 2).

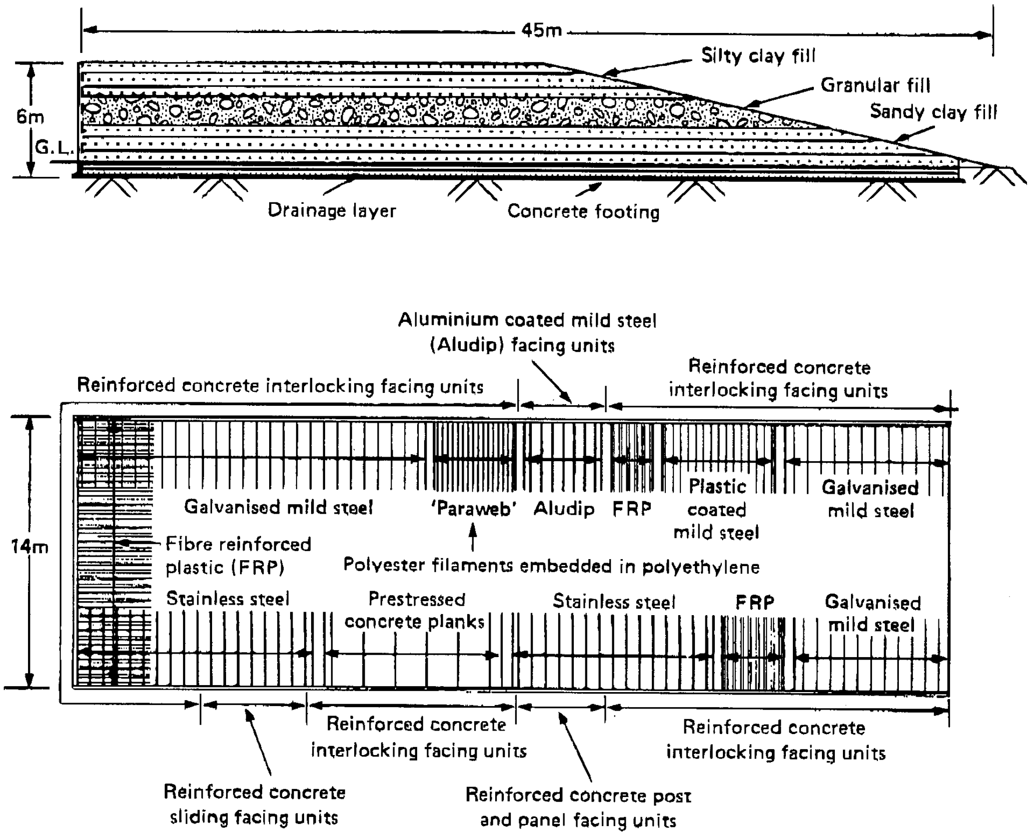

Figure 1. Layout of the trial wall at the Transport and Road Research Laboratory in Crowthone, UK, 1977.

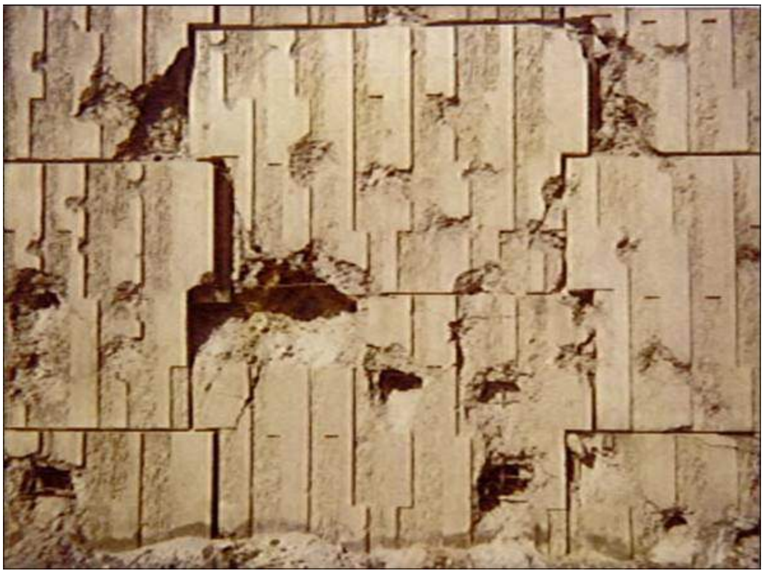

Figure 2. Effects of Gulf War missiles on walls on the Fahaheel Expressway, Kuwait in 1991.

THE KINALI – SAKARYA MOTORWAY PROJECT, ISTANBUL, TURKEY

The Turkish section of the Trans-European Motorway runs from Edirne, near the Bulgarian/Greek border to Istanbul (Thracian Motorway) and then on to the capital city Ankara (Anatolian Motorway). The motorway consists of two main sections: Edirne to Kinali; and Kinali to Sakarya. The Kinali-Sakarya section which commenced in 1987 and completed in 1993, including the Camlica-Gebze Section, extends from approximately 80km west of Istanbul to almost 200km east of Istanbul. It is the first of a series of motorway projects to be constructed in Turkey and considered as "the motorway that sets the new standards".

Mainly on the European side of the Kinali Sakarya section starting from Bahcesehir to the Second Bosphorus Crossing (Fatih Sultan Mehmet Bridge) on a stretch of 30km (Figure 3), all the wing walls of the overpasses and the retaining walls of the connecting roads from the motorway to the existing circular road were constructed with a reinforced soil system using polymeric strips. The wall area constructed was more than 60,000 sq.m.

Figure 3. Location of reinforced soil walls with polymeric strips on the Kinali-Sakarya Motorway and the epicentre of the 1999 Kocaeli Earthquake.

Design and construction of the K – S Motorway reinforced soil walls

The purpose of many of the retaining walls, some as much as 18m high, was to support steep cut faces as the Motorway went through hills on the approaches to the second Bosphorus Bridge. This necessitated a cross-section shape which was trapezoidal, being narrow at the base and wide at the top to follow the line of the cut. The width at the base was taken as not less than 0.4 x the mechanical height. Generally the design was done to the French Code at the time, “Reinforced Earth Structures – Recommendations and Rules of the Art”. Today this would be very similar to the coherent gravity method described in BS8006. Fill within the walls was assumed to have an angle of internal friction of 40^0 while the cut slope was taken as having an angle of internal friction of 50^0. Typically the ‘overall’ factor of safety on reinforcement rupture worked out at 2.7. A typical wall section is shown in Figure 4 and a section of wall under construction is shown in Figure 5. A nearly completed wall is shown in Figure 6.

The French Code at the time provided for seismic design using simple static principles of the Mononabe-Okabe type. This involved an enhancement of the lateral earth pressures proportional to the intensity of the expected seismic event. However it was considered, in view of the height of some of the structures, the importance of the project and the unusual shape of the wall cross-section that a further dynamic analysis should be done. This was carried out by the Geotechnical Consulting Group in London. The object of the analysis was to determine the acceleration required in the seismic event to cause the structure to displace outwards. This ‘Critical Acceleration’ was calculated by optimising wedges through or beneath the structure. The displacement of the wall, assuming that brittle failure would not take place, was calculated using the Newmark sliding block analogy. The average seismic coefficient was taken as 0.3. (Bracegirdle, 1979).

The dynamic assessment of the design concluded that it would be most unlikely for the reinforcing strips to rupture before the structure began to fail in shear. Such shear planes would start at a fairly high angle but flatten to close to horizontal as the reinforcement tensions increased and the soil shear strength was mobilised. It was estimated, with continued shaking, that reinforcement tensions could increase to significantly above the design load but would decay after shaking ceased. Present day residual strength approaches to seismic design for polyester based reinforcements demonstrate that such increases can be easily accommodated. Displacements using the Newmark method were assessed to be below 46mm in the design acceleration used which is well within normal serviceability limits for a wall.

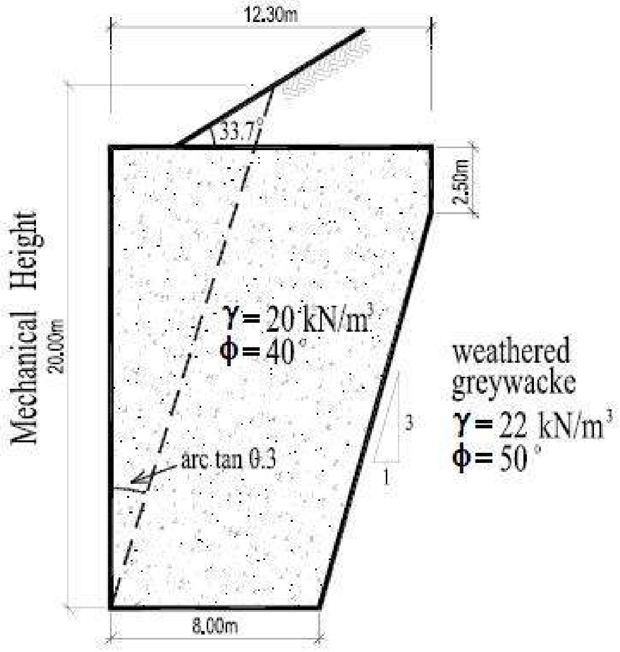

Figure 4. Typical wall cross-section.

Figure 5. Wall under construction with 'Greywacke' cut face on left and reinforcement elements laid out.

Figure 6. Precast yard and nearly completed wall behind.

The Kocaeli Earthquake in 1999 and its effect on reinforced soil walls

On 17th August 1999 a magnitude MW 7.4 earthquake struck the Kocaelis and Sakarya provinces in north western Turkey, a densely populated region in the industrial heartland of the country. In terms of destruction and loss of life this earthquake was one of the world's worst during the 20th Century (Ansal et al, 1999). The earthquake developed at a depth of about 15 km and around 10 km to the east of the town of Golcuk (Figure 3). It is associated with a 120 km rupture involving four distinct fault segments on the northern-most strand of the Western extension of the 1300 km long North Anatolian fault system (Erdik, 2000). Istanbul also felt the earthquake and several buildings collapsed causing loss of lives in the districts such as Avcilar, Kucekcekme (on the European side) which are a few kilometres from the site of a number of reinforced soil walls. None of the polymeric reinforced soil walls was damaged. One Reinforced Earth wall close to the epicentre was badly affected by the event in terms of serviceability (Figure 7) and was subsequently demolished. Pamuk et al (2004) discussed the performance of the failed metallic strip Reinforced Earth wall in detail.

Figure 7. Reinforced Earth wall damaged in the Kocaeli Earthquake prior to demolition.

The opportunity to recover polymeric strip materials for test

In late 80s and early 90s the route of the motorway was passing unpopulated areas. Presence of the motorway and the connecting roads brought the opportunity to inhabit these areas and new settlements were established. The growth of these areas and the increase of traffic on the connecting roads were exponential and could not serve the needs of the area. The Istanbul Metropolitan Municipality has planned new junctions and widening of connecting roads to ease the transportation to these new settlements. For this purpose a new junction construction located at Seyrantepe has been planned to enable exit and entrance to the motorway. Within the scope of the project the two span existing overpass was to be demolished and replaced with a four span overpass. The wing walls of the existing overpass were polymeric reinforced soil walls. Therefore the demolition of the overpass brought the opportunity to recover polymeric strips. The location of the overpass was on a section of the motorway where there was heavy traffic 24 hours a day. Unfortunately there was not enough time to recover strips with hand excavation so the fill was excavated behind the panels with the help of a backhoe (Figure 8) and the polymeric strips at the connections to the panels were cut and the panels were removed letting the fill flow. Therefore only the strips that were hanging from the embankment could be recovered with minimal damage (Figure 9)

Figure 8. Demolition of the polymeric reinforced soil wall.

Figure 9. Recoverable polymeric strips from the embankment.

Testing of the polymeric strip materials recovered from the K – S polymeric reinforced soil wall

A number of samples were recovered from the demolished wall and were available for test so that they could be compared with the behaviour of the materials at the time of installation. Tensile tests were carried out using similar techniques to those used in the 1980's although some improvements in the equipment used may have a minor effect on the results. The mean tensile test results, expressed as a percentage of the ultimate load, are shown in Figure 10 and compared with the expected behaviour of the original material as shown in BBA Certificates No's 82/22 and 88/38, both entitled 'Websol Frictional Anchor System' and that measured for the virgin material used in the 1977 TRL wall (Naughton et al., 2005). The polymeric strips exhumed was grade 50 which would have had a Nominal Breaking Load (NBL) of 50 kN but an actual breaking load of closer to 60 kN with a strain at NBL of around 11%.

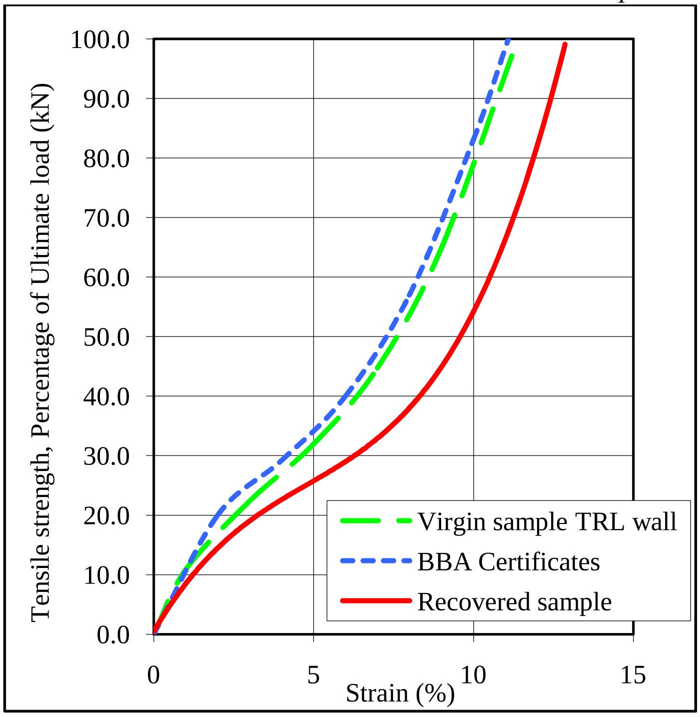

Figure 10. Results of tensile tests carried out on exhumed 50kN Paraweb samples compared with virgin material.

SUMMARY AND CONCLUSIONS

1. Reinforced soil walls using polymeric strip materials have now been in service for over 30 years. The first was a trial wall built by TRL in the UK in 1977, the performance of which provided information that resulted in design guides being produced and which subsequently contributed to the publication of BS8006:1995;
2. Samples of polymeric strip materials are periodically taken from the TRL wall which have confirmed by test that the long-term properties of the materials remain as anticipated;
3. Since the successful implementation of the TRL wall many wall structures have been constructed using polymeric strip materials in a large number of countries in a broad range of climatic and environmental conditions;
4. In the late 1980's a large number of walls were built to form part of the Kinali-Sakarya Motorway close to Istanbul in Turkey on the approaches to the Second Bosporus Bridge. These structures were designed to withstand seismic conditions using both static and dynamic design procedures;
5. In 1999 these structures and a metallic reinforced Reinforced Earth structure were subjected to an earthquake which was recorded as having an intensity of magnitude MW 7.4 with an epicentre at Golcuk to the south of Istanbul. The Reinforced Earth structure suffered serious serviceability damage resulting in subsequent demolition and replacement. The polymeric strip reinforced soil walls all survived the earthquake with no signs of distress or movement;
6. In 2007 one of the polymeric reinforced soil structures was demolished for the purpose of road widening and the construction of a larger motorway junction. This provided the opportunity to recover the polymeric strips manufactured and installed in 1987 for testing after some 20 years of use and having been subjected to the 1999 earthquake. The results of these tensile tests showed that the materials had not lost any strength during the period of use nor during the earthquake event. Little apparent change had occurred either in the strain behaviour over the year's of use.

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REFERENCES

Ansal, A., Bardet, J-P., Bray, J., Cetin, O., Durgunoglu, T., Erdik, M., Kaya, A., Ural, D., Yilmaz, T. and Youd, T.L. 1999. Initial Geotechnical Observations of the August 17, 1999, Izmit Earthquake. A Report of the Turkey – US Reconnaissance Team.

BBA Certificate No. 78/601, The Websol System of Soil Reinforcement

BE3/78, UK Department of Transport Technical Memorandum Reinforced and Anchored Earth Retaining Walls and Bridge Abutments for Embankments

Bathurst, R.J., Hatami, K. & Alfaro, M.C. 2002. Geosynthetics and their applications, Chapter 14, Geosynthetic-reinforced soil walls and slopes – seismic aspects. Edited by Shukla, S.K. Thomas Telford publication.

Boden, J.B., Irwin, M.J. & Pocock, R.G., 1977. Construction of experimental reinforced earth walls at the TRRL. Symposium on Reinforced Earth and Other Soils Techniques, Heriott-Watt University, Edinburgh.

Bracegirdle, A. 1979. Reinforced Earth Walls static and dynamic considerations. M.Sc. Dissertation, Imperial College, London University.

Brady, K.C. 1987. Performance of reinforced earth bridge abutment at Carmarthen. TRRL Report 111.

Brady, K.C., Barratt, D.A. & McMahon, W., 1995. Long term monitoring of a reinforced earth bridge abutment at Carmarthen: 1984 to 1994. TRL Report No. 124.

Erdik, M. 2000. Report on 1999 Kocaeli and Duzce (Turkey) Earthquakes. http://www.koeri.boun.edu.tr/depremmuh/eqspecials/kocaeli/kocaeli_eq.htm

Greenwood, J.H., Kempton, G.T., Brady, K..C. & Watts, G.R.A., 2004. Comparison between stepped isothermal method and long-term creep tests on Geosynthetics, Proceedings of the 3rd European Conference on Geosynthetics, Munich, 527 – 532.

John, N.W.M. et al, 1983. Instrumentation of reinforced soil walls. Proceedings of the 8th European Conference on Soil Mechanics and Foundation Engineering, Helsinki, 509 – 512.

Kempton, G.T., Entwistle, R.W. & Barclay, M.J., 1985. An anchored fill harbour wall using synthetic fabrics. Proceedings of the Institution of Civil Engineers, Part 1, 78, April, 327 – 347.

Naughton, P.J., Balderson, T. & Lozano, R. 2005. The properties of polyethylene encased high tenacity polyester linear elements. Geosynthetics and Geosynthetic Engineered Structures, Contributions from the Symposium Honoring Robert M Koerner, Ed Ling, H.I., Kalialin, V.N & Leshchinsky, D, 19 – 38.

Özçelik, H. 2006. Measurement of panel deformations of a polymer reinforced soil bridge abutment. Proceedings of the 8th International Conference on Geosynthetics (8IGC), Yokohama, 1125 – 1128.

Pamuk, A., Ling, H.I., Leshchinsky, D., Kalkan, E. & Adalier, K. 2004. Behaviour of reinforced wall system during the 1999 Kocaeli (Izmit), Turkey earthquake. Proceedings of the 5th International Conference on Case Histories in Geotechnical Engineering, New York, April 13 – 17, Paper No. 3.45.