Case Study : Hybrid MSE wall system used on a highway project in Turkey

H. Özçelik
Tekno Maccaferri A.S., Istanbul, Turkey

ABSTRACT: The road to Demirkent village on the way from Yusufeli to Artvin, located at the north-east of Turkey had to be relocated as it will be flooded by the reservoir of the Artvin Dam. The retaining structures supporting the relocated road, designed using hybrid structures made up of gabion baskets produced from double twist wire mesh as the facing element and high strength geogrids, were constructed on the right bank of the reservoir between tunnels T6 and T7. Eight walls, having a total surface area of nearly 11,000 sq.m , reaching a maximum height of 25.0 meters, were the first hybrid MSE walls of its kind built in a highway project in Turkey. The area is located in the second degree seismic zone of Turkey. The design of walls has been carried out using pseudo-static method (limit equilibrium) taking into consideration different loading conditions using Eurocode 7. For each standard approach stability analyses in static and seismic conditions were performed. The paper deals with the detailed design of the MSE wall system and the construction methods; advantages of using such system for the project are discussed.

Keywords: [gabion, geogrid, MSE wall, reinforced soil wall, soil reinforcement]

1 INTRODUCTION

Artvin Dam constructed at the north – east part of Turkey (Figure 1), is located between the province Artvin and its district Yusufeli. The access road to the Demirkent village from Yusufeli – Artvin road shall be flooded by the reservoir of the Artvin Dam. The new re-located road shall be elevated and constructed on the slope of a hill at the right bank of the reservoir. The project is privately financed and constructed on build – operate – transfer basis.

The design of MSE walls has been carried out using pseudo-static method (limit equilibrium) taking into consideration different loading conditions and different geometrical features. The stability analyses checks are carried out for every wall heights using Eurocode 7 for static and seismic conditions with a Peak Ground Acceleration, PGA=0.3g.

This paper, in addition to the detailed design, describes the construction stages starting from preparation of the foundation, laying of geogrids, unfolding of the gabion baskets, installing them into position, filling them with rock, sewing the top lids, backfilling, installing geogrid reinforcements and advantages of using such system for the project. Summary of the static and seismic analyses, the design layout and the construction stages are explained, with typical section, details and pictures during construction.

2 REINFORCED SOIL CONCEPT

An analogous to reinforced concrete, reinforced soil is a soil mass, strengthened with tension elements that are able to handle tensile strains by means of friction created between the element and the soil. The system was first used in retaining walls in early 70s and with the introduction of geosynthetics in late 80s, geogrids became more popular in MSE wall constructions.

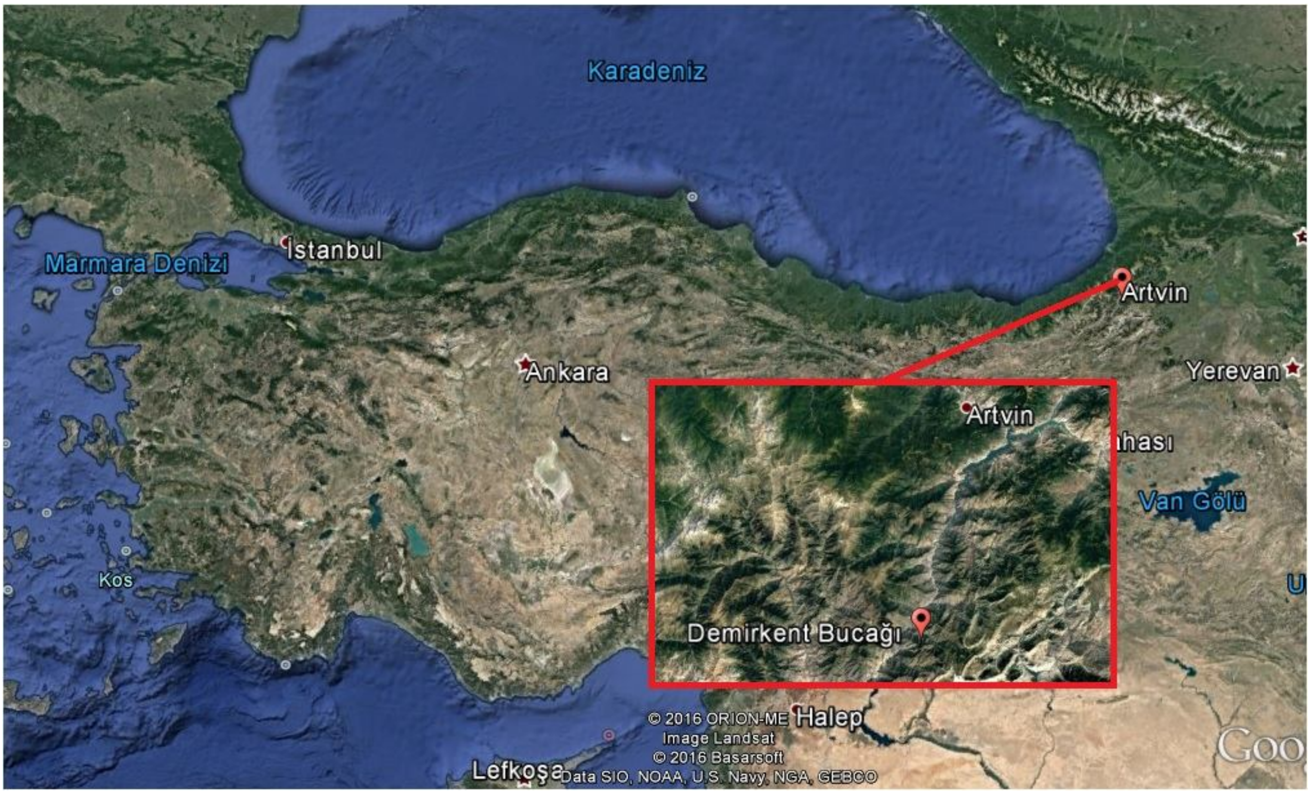

Figure 1 – Location of the Artvin Dam, north – east of Turkey

2.1 *Hybrid reinforced soil structures*

The MSE wall system used in the project is Terramesh® Wall System, which is a modular system used for soil reinforcement applications and is composed of polymeric geogrids as the main reinforcement and gabion facing produced from double twisted wire mesh acting as secondary reinforcement for face stability. The system is the most flexible, detailed and complete reinforced soil system present and can easily be employed in seismic areas even though they are subject to large loads like 200kPa overburden pressure, Özçelik et. Al. (2014).
When the re-located road is elevated and designed on a slope, it was evident that retaining structures are necessary. A hybrid MSE wall system, made up by the combination of a gabion basket and high strength geogrids has been adopted for construction of the vertical retaining structures. The system is based on the principles of soil reinforcement where tensile elements, i.e. high strength polymeric geogrids, are introduced in the soil mass as reinforcement to retain the soil vertically by virtue of interaction between soil and reinforcing elements. Schematic arrangement of the MSE wall system is shown in Figure 2.
Facing elements are comprised of gabion units, formed by double twisted steel wire mesh produced from heavily Galmac (Zn-Al5% alloy) and PVC coated steel wires having diameters of 2.7 - 3.7mm which are used for vertical reinforced soil wall. The MSE wall system consists of a gabion basket at the front with integrated tail of double twist steel wire mesh, as shown in Figure 2. The tail acts as secondary reinforcement in the system, holding the facia panels in position by the virtue of interaction with frictional soil fill.
ParaGrid geogrids are planar structures consisting of a mono axial array of composite geosynthetic strips. High strength strips, used as main tensile element or primary reinforcement, are manufactured from bundles of high molecular weight and high tenacity polyester yarn, coated with a polyethylene sheath. High strength geogrids are formed by uni-axial arrangement of these high strength strips connected to each other at intermittent intervals by transverse polymeric strips of lower strength, Özçelik et. al. (2014). It is a durable material engineered to mechanically and chemically resist biological degradation normally found in soils.

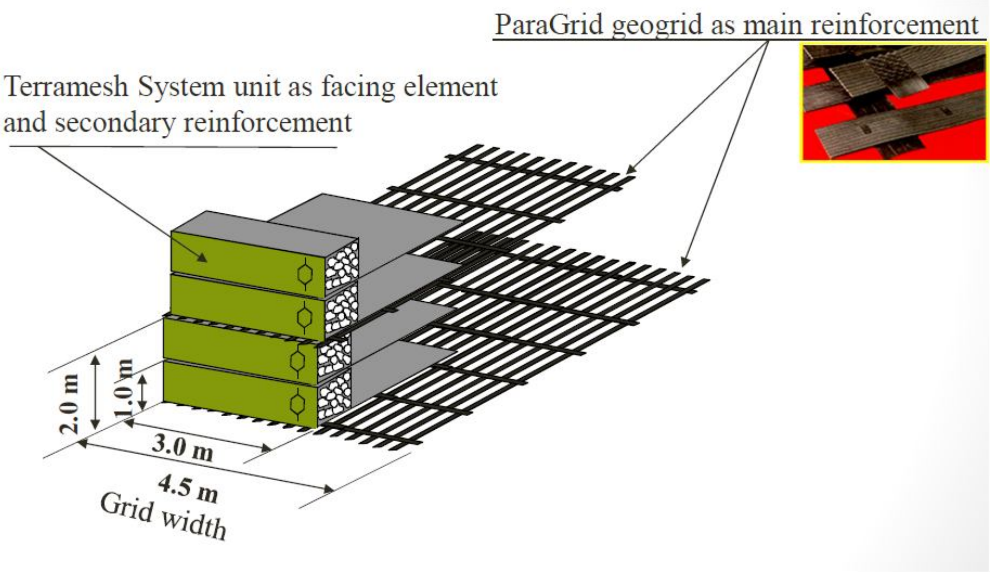

Figure 2. Arrangement of the MSE wall system with gabion facing and the geogrids

2.2 *Project description and given input data*

2.2.1 *Geological input data*

The MSE wall system is built on sloping ground between the western Yusufeli formation of agglomerate, shale, tuff and siltstone, and the Demirkent formation of gabbro, intersecting dikes of granite, volcanic tuff and agglomerate to the east. Slopes of the hill are covered with slope debris. About 70% of the MSE wall foundations are located on Yusufeli formation and 30% on Demirkent formation. During construction, most of the foundation levels are revised in order to reach the sound formation by excavating the slope debris.

2.2.2 *Project site and characteristics*

A total of eight walls was constructed to support the road which rests on the hilly rough terrain and because of the level differences tall retaining structures are required. The retaining structures supporting the road are designed using hybrid structures made up by the combination of two types of reinforcements the gabion baskets and high strength geogrids. The main reason for selecting this type of wall is its flexible nature and conventional retaining structure cannot be economic in such an area. As the project is part of a large dam construction, a detailed seismic hazard for the site has been defined and a detailed site response analysis was developed. In order to calculate the seismic coefficients $\mathbf{k_h}$ and $\mathbf{k_v}$ to be used in pseudo-static analysis, the average value of peak acceleration profile along the height of each retaining structure, was defined wall by wall on the basis of detailed site response analysis. Eight walls having a total surface area of nearly 11,000 m^2 reaching a maximum height of 25.0 meters were designed and constructed in just 7 months. Seven culverts, of which one is integrated through the MSE wall system, were constructed for the surface drainage of the slopes.

3 TECHNICAL SOLUTION

3.1 *Selection of reinforced soil structures*

The required retaining structures are very tall. Thus any system selected for construction of retaining structures had to be flexible to withstand settlements and high earthquake forces.
Conventional masonry and RC retaining walls were ruled out due to the prevailing extreme site conditions as described above. A flexible retaining wall with a free draining facia was an ideal choice for this terrain

due to its inherent ability to accommodate settlements and vibrations due to dynamic forces. It was also known that for tall MSE walls, the effects of compressibility and settlements were completely absorbed by the gabion facing, Ananias et. al. (2016). The selected MSE wall system, as reported by Tanyu et. al. (2016), was inundated with over 3.9m of rain and 6.9 magnitude earthquake without any visible sign of distress.

3.2 *Design aspects*

The reinforced soil structures have been built using fill coming from the excavation of the tunnels which is blasted rock. Such a soil can be assimilated to the group boulders and cobbles (material retained on the 75mm sieve) as per ASHTO M145-91 classification and should not contain particles greater than 250mm. Compaction of structural soil (to a density ≥ 95%) has been achieved at each lift. The degree of compaction was checked on a test pad and the number of passes of the vibro-roller (>10 tons) necessary to achieve the required compaction degree was determined. As the fill contains large particle sizes reaching 250mm, the compaction was checked by measuring the level difference of the compacted fill level after the last two passes of the vibro-roller which was less than 5mm.
The geotechnical model was developed according to the worst conditions with the characteristics listed in Table 1. Tests performed on the MSE wall system units in laboratory determine the equivalent cohesion of the unit due to the presence of the mesh. The cohesion evaluated according to empirical relationship is reported and the MSE wall system unit's properties were also listed in Table 1.

Table 1. Geotechnical model of the soils

Soil type→ Properties	Structural Soil	Natural Soil	Gabion facing
Friction angle, ϕ°	37.0	30.0	40.0
Cohesion, c (kPa)	5.0	20.0	12.5
Unit weight, γ (kN/m³)	19.0	19.0	17.5

Ultimate Limit State principles (ULS) are applied to the design of reinforced soil structures. The design has been carried out under both static and seismic condition, adopting the pseudo static method.
According to Eurocode 7 - UNI EN 1997-1 partial factors are applied; nominal loads are increased by multiplying by prescribed load factors "γ_G"and "γ_Q" greater than unity for loads with a disturbing effect, to obtain design loads.
Material properties such as reinforcement strength or soil properties are reduced by dividing by prescribed material factors "γ_m" (greater than unit), to produce design material properties. Resistances such as soil shear resistance or bearing capacity are divided by prescribed resistance factors "γ" (greater than 1.0).
For the stability checks it has been verified that a limit state of rupture will not occur with the combinations of set of partial safety factors as for:

Design Approach 2 : A1+M1+R2
Design Approach 3 : A2+M2+R1
Pseudo-static approach : M2+R1+kh±kv

In this regard, the parameter is evaluated for design resistance. The estimation of the design resistance of work of the reinforcing elements has been determined by reference to the diagram shown below according to BS 8006 standard.
The design resistance $\mathbf{T_d}$ is evaluated according to the formula:

$$\mathbf{T_d = T_b / f_m}$$

where $\mathbf{f_m}$ is the overall safety factor applied to the nominal tensile strength $\mathbf{T_b}$, to obtain the design tensile strength $\mathbf{T_d}$, which is indicated according to the chart shown below.

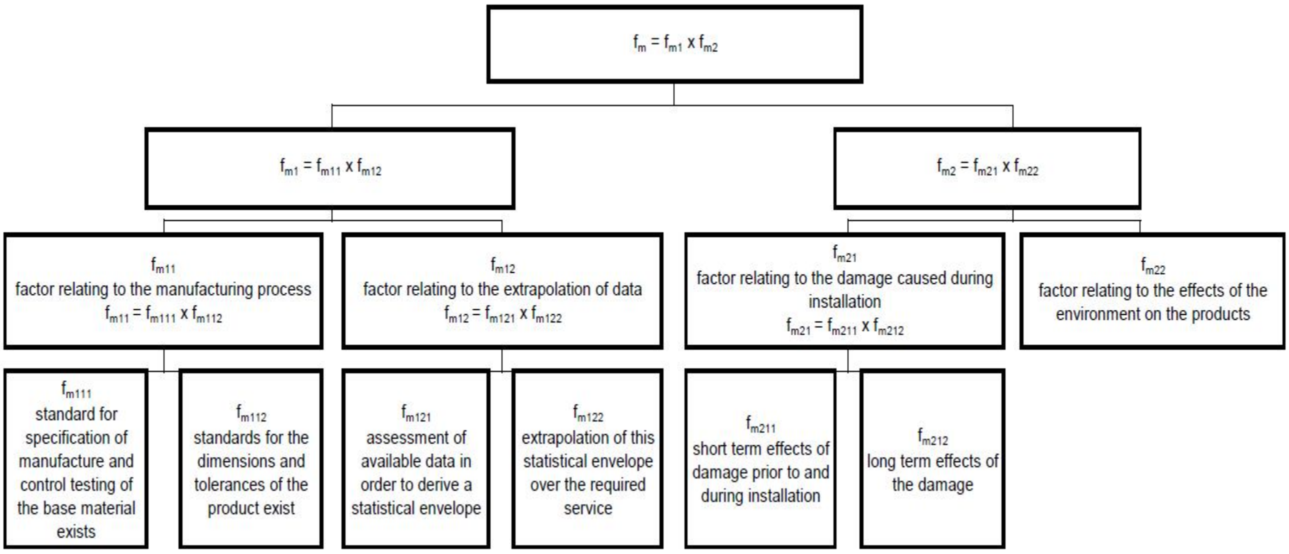

Table 3 shows the tensile strength for the reinforcements used in the design and the value of the safety coefficients f_m and f_{creep}.

Table 3. Tensile strength for the reinforcements and the safety coefficients f_m and f_{creep} used in the design

	UNIT	GEOGRID 80	GEOGRID 100	GEOGRID 200	GABION BASKET 3x3x1x0.5 (mesh 8x10 wire 2.7/3.7mm)	GABION BASKET 3x3x1x1 (mesh 8x10 wire 2.7/3.7mm)
Ultimate tensile strength (UTS)	kN/m	80	100	200	50.11	50.11
Residual tensile strength percentage **f_{creep}**, % of UTS	%	72.36	72.36	72.36	100	100
Global safety factor - **f_m**		1.10	1.10	1.10	1.30	1.30
Design tensile strength	kN/m	**52.63**	**65.78**	**131.56**	**38.50**	**38.50**

Due to the variations in topography, the structure height had to be varied for several sections; detailed stability analyses were carried out on representative sections of the hybrid reinforced soil structure. The cross section of the MSE wall at chainage 1+380 having a maximum height of 25.0m is shown in Figure 3.
All stability checks were performed using the proprietary software, MacStARS, based on a limit equilibrium approach. Traffic load is considered with an equivalent of 15kPa surcharge load. A typical output of MacStARS and the "safety map" of the potentially sliding surfaces are shown in Figure 4 and 5 respectively where the failure surfaces, represented with different colors in relation with the values of the Factor of Safety. For the tallest cross-section (H=25.0m) the stability calculations afforded the results summarized in Table 2.

Table 2. Results of stability calculations for the tallest cross-section of the MSE wall system

Stability calculations→	Overall	Sliding	Overturning	Bearing Capacity	Internal Stability
Loading combinations					
Seismic: M2+R1 (+ k_v)	1.210	1.270	1.554	1.208	1.392
Seismic: M2+R1 (- k_v)	1.119	1.408	1.710	1.127	1.461
Static : A2+M2+R3	1.542	2.823	4.324	1.558	1.544
Static : A1+M1+R2	1.600	3.040	5.520	1.637	1.603

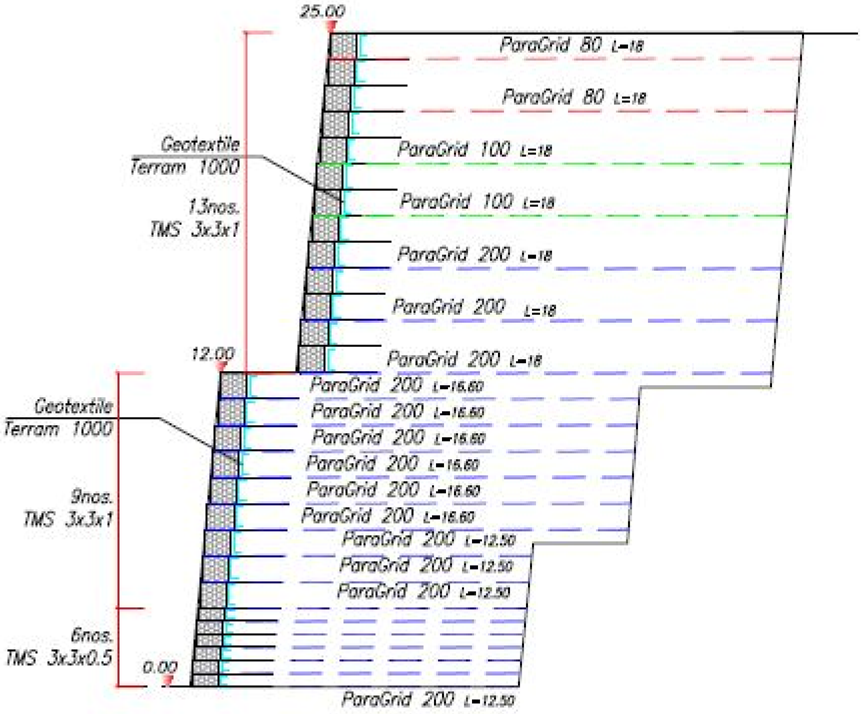

Figure 3. Tallest cross section (H25.0m) of the MSE wall system

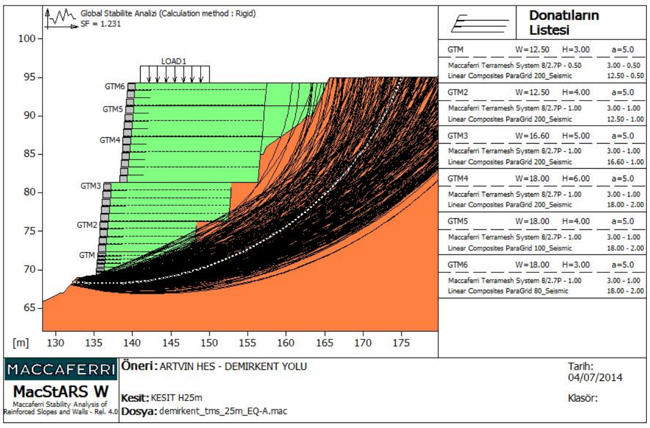

Figure 4. Typical MacStARS output for Wall-3

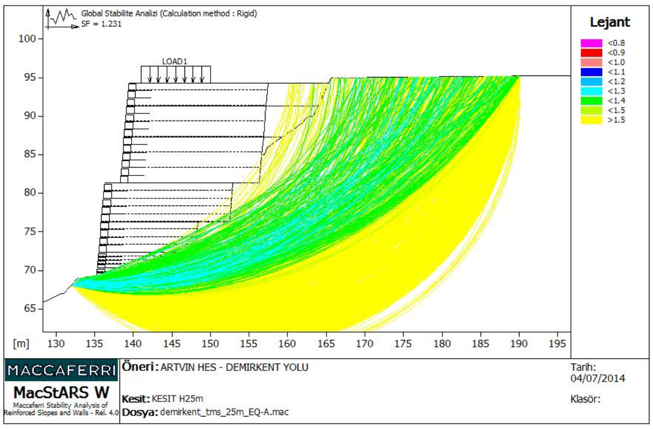

Figure 5. “Safety map” of the sliding surfaces for Wall-3

4 CONSTRUCTION STAGES

The construction stages of the MSE wall system supporting the Demirkent village road constructed between T6 and T7 tunnels (Figure 6-a and b), are explained below. The construction stages consist of foundation preparation, installation of geogrids, installation of gabion boxes, filling of gabion baskets and backfilling operations summarized below were described by Özçelik et. al. (2014).

4.1 *Foundation preparation*

The foundation on which the gabion baskets and geogrids are to be placed shall be leveled, and graded to the elevations as shown on the project construction drawings. The foundation shall be smooth, without surface irregularities, voids, loose material, vegetation and roots.

The geogrids are the primary reinforcement in the MSE wall system. Geogrids shall be laid starting from the outer alignment of the wall and unrolled perpendicular to the gabion baskets. The geogrid roll (4.5m wide) must be cut to the design length required for the first layer and, the consecutive layers.

Figure 6. a) Demirkent-2 Tunnel, Demirkent direction b) Demirkent-1 Tunnel, Artvin-Yusufeli direction

4.2 *MSE wall system units installation*

The MSE wall system units are actually gabion baskets with an added tail portion at the back. The tail is actually the continuation of the top lid, front face and the bottom of the gabion basket forming a monolithic element. The units shall be first opened and unfolded. The facing section of the units shall then be assembled individually by erecting the back+ends, and diaphragms, ensuring that all panels are in the correct position, and that the tops of all sides are aligned. The four corners of the facing box shall then be connected first, followed by the internal diaphragms to the outside walls facing. All connections shall be made using steel lacing rings.

The MSE wall system units shall then be placed along the outer line of wall facing previously marked on the foundation level. The units are placed on top of the geogrid with the gabion portion forming the facing of the wall. The MSE wall system units shall be connected to the adjacent units along all the vertical and top+bottom edges of their contact surfaces by steel lacing rings.

4.3 *Filling the gabion baskets with stones*

Rocks for filling the MSE wall system shall be hard, angular to round, durable and of such quality that they do not lose their integrity on exposure to water or weathering during the life of the structure. Rocks shall range between 125 mm and 250 mm. To obtain a good appearance of the gabion basket facing, the use of wooden formworks is required. The formwork enables to achieve the uniformity in the facing box dimensions during the filling and placement of stones for a good aesthetic appearance. After the placement of a layer of rock in the cell, in order to minimize voids and achieve a maximum density, the rocks shall be adjusted by hand. The outer face of the gabion baskets should be carefully hand placed to give a neat, flat, and compact appearance. At the back face of the MSE wall system unit, a non-woven geotextile shall be fixed as a separation boundary between the compacted fill and the rocky material inside the gabion basket.

4.5 *Backfilling*

The structural fill shall be carefully placed and compacted in the area behind the MSE wall system units extending up to the end of design reinforcement length. The structural fill shall be placed in layers. Great care should be exercised when placing, spreading and compacting the fill, ensuring that the heavy machinery is kept away from the area immediately behind the MSE wall system units for 0.5m.

Figure 7. Various stages of the construction and the completed walls

Compact the soil to the required level and make sure that the roller always moves in a direction parallel to the direction of the wall. The roller shall never move in a direction perpendicular to the direction of the wall.

In no circumstance should the fill material be pushed directly towards the MSE wall system units, particularly in the area immediately behind the units. During compaction, the movement of vibro-roller (>10 tons) shall not be permitted closer than 0.5m from the rear face of the MSE wall system unit. The compaction within 0.5m from rear face of the unit shall be carried out by patch rollers or vibratory plate compactors. Various stages of the construction are shown in Figure 7.

5 CONCLUSIONS

1. A hybrid reinforced soil wall system was employed for the 25.0m high retaining walls in a road re-location project located in the north – east part of Turkey.
2. The system is composed of geogrids as the primary reinforcement and gabion facing and steel grids as secondary reinforcement giving the flexibility to tailor various cross sections
3. The system is the most flexible, detailed and complete reinforced soil system present
4. A free draining facia i.e. the gabion facing with tail, was an ideal choice for this high terrain at very steep slope due to its inherent ability to accommodate settlements as the gabion facing absorbs such deformations
5. The system used was the most cost effective and most practical solution utilizing an efficient combination of polymer and steel wire reinforcement behind a rock filled gabion basket facing
6. The construction was carried out on build – operate – transfer basis, therefore the client preferred to construct the most economic, quick and maintenance free MSE wall system.

6 ACKNOWLEDGEMENT

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7 REFERENCES

AASHTO M 145-91 (2012) Standart Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

Ananias, E. J., Geraldo V. and Wolle, C. M. (2016) Performance of 23m high MSE wall with polyester geogrids and Terramesh system facing through the monitoring of deformations, *Geo-Americas 2016, 3rd Pan-American Conference on Geosynthetics,* 10-13 April 2016, Miami Beach, USA

BS 8006-1:2010 "Code of Practice for Strengthened / Reinforced and Other Fills", British Standards Institution

Eurocode 7: Geotechnical Design – Part 1: EN 1997-1 (2004) General Rules, European Committee for Standardization, Bruxelles, Belgium

Özçelik, H., Gamberini, D., Pezzano, P. and Rimoldi. P. (2014) Geogrid and double twist steel mesh reinforced soil walls subjected to high loads in a seismic area. *10ICG, 10th International Conference on Geosynthetics*, 21-25 September 2014, Berlin Germany, Paper No:10

Tanyu, B. F., Abbaspour, A., Collin, J. G., Leshchinsky, D., Han, J., Ling, H. I. and Rimoldi, P. (2016), Case study : Instrumentation of a hybrid MSE wall system with up to 2m vertical spacing between reinforcements, *Geo-Americas 2016, 3rd Pan-American Conference on Geosynthetics,* 10-13 April 2016, Miami Beach, USA