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Back-to-back Mechanically Stabilized Earth Wall over a Load Transfer Platform supporting a railway structure: design consideration and installation procedure

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ABSTRACT
The Reading Viaduct represents one of the longest concrete viaducts in the UK and it carried its first train on January 4th 2015. The £45 million structure is 2 km long and was designed to ease the bottleneck which had troubled the railway system in the area for years. This viaduct relieves the passenger train services, no more waiting for slower freight trains to pass. The installation of the viaduct required long approach ramps to be constructed to raise the line approximately 6 m at both ends. The working area was within 15 m from the existing operational rail line, therefore conventional earthworks were not feasible. A Mechanically Stabilized Earth (MSE) solution with discrete concrete panels and polymeric reinforcing strips was chosen to support the ramps. The project comprises one side MSE structures and tied back-to-back walls of 10 m width adjacent to the viaduct. To provide a suitable foundation for the train loaded ramp/MSE structures, ground improvement was necessary, due to the variable nature of the existing soils. A high strength geogrid reinforced Load Transfer Platform (LTP) was designed to absorb, spread and dissipate applied loads vertically downwards into the piled ground. The aim of this paper is to present the solutions chosen for this project, detailing the design of the complex back-to-back MSE walls and Load Transfer Platform.

Key words: geostrips, back-to-back, MSE wall, railway, Load Transfer Platform

1. INTRODUCTION

Mechanically Stabilized Earth (MSE) walls with polymeric reinforcements and concrete facing panels, are well-known systems used worldwide to enable the construction of infrastructure in tight urban corridors, forming retaining walls, abutments and wing walls. Nowadays, MSE technology with polymeric reinforcements is considered a suitable solution also for railroad, particularly where the non-corrodible nature of geostrip to stray electrical currents make them suitable for application close to a catenary system.
The Reading Viaduct project is part of the plan to improve the railway traffic flow in Reading. The new structure includes the construction of three MSE approaching ramps combined with polymeric strips and Load Transfer Platform (LTP) to dissipate the embankment loads into the piled ground. The design includes a back-to-back ramp serving the southbound spur which has a panel facing to the both sides due to the vicinity of the adjacent viaduct. This paper presents the design MSE system and Load Transfer Platform.

2. BACKGROUND

Every year, more than 3.8 million passengers pass through Reading railway station, the major transport hub in Reading, England. Due to the huge traffic volume, the station had become a bottleneck in the railway network with passenger trains often needing to wait outside the station for a platform to become available. The main cause was related to the limited number of through-platforms, flat junctions east and west of the station and the need for north-south trains to reverse direction. In 2007, the Department of Transport announced a plan to improve traffic flow at Reading by investing £895million in 4 years. £45 million was dedicated to the construction of a new viaduct built by Balfour Beatty construction group.
The viaduct consists of three long approaching ramps designed to work within 10 m of the existing operational rail line. Due to the space constraint, ramps were designed as vertical reinforced soil walls with discrete concrete panels on one side or both sides, depending on the project geometry.
The project also included the demolition of the original train depot to the south to make way for the new viaduct. The construction of the viaduct started in the spring of 2013 and was completed in July 2014.

3. PROJECT CONSIDERATIONS

The three soil reinforced ramps were designed by an engineering consultant company with Maccaferri technical team support. The system chosen is commercially known as MacRes and it is made up of concrete facing panels and ParaWeb polymeric reinforcing strips. The West ramp incorporates 800 m^2 of concrete panels while the East ramp is 1350 m^2. Both West and East ramps are realized with the MSE wall system on one side and a 1:2 slope on the other side. The third ramp, called Festival ramp, consists of a 450 m^2 back-to-back MSE wall with a 5.80 m wide base and a maximum height equal to 3.60 m.

The structure, designed according to BS 8006-1:2010 chapter 6.6, behaves like a semi-rigid structure able to accommodate differential settlements. A site investigation confirmed that the existing ground had a shear strength of 25 kPa and did not have enough bearing capacity to support the overturning moment generated by the MSE wall and rail loads. Therefore, Network Rail designed a ground improvement consisting of vibro-concrete columns (VCC) with a geogrid reinforced Load Transfer Platform (LTP) able to transfer the embankment loads ensuring settlement would be kept within the acceptable limits as per railway applications.

4. LOADS TRANSFER PLATFORM

Vibro-concrete columns (VCC) consist of vertical columns, designed to transfer the loads coming from the three ramps of the viaduct, through the soft compressible soil layer to a firm foundation.
The design of the columns was carried out by the main contractor and built with approximately 2300 piles 7.2m long and 450mm diameter. The arrangement of the piles is based on a square grid with 1.86m spacing for the Festival Line and 1.58m spacing for the West ramp. The East ramp VCCs have been reduced to spacings which vary between 1.44m and 1.86m.
In order to minimize the number of columns and to better transfer loads of the embankment to the pile caps, a Load Transfer Platform (LTP), made by a geogrid mattress, was placed on top of the piles and a circular cap with a minimum diameter of 600mm was designed. The geogrid reinforcement counteracts the horizontal thrust of the embankment fill, eliminating the need for raking piles along the extremities of the foundation.
The LTP was designed for a structural life of 120 years. The live/surcharge loads data were taken from the project specification and applied across each section in accordance with BS EN 1991-2: Traffic load for bridges.
Table 1 summarizes the maximum applied load in each ramp:

Table 1. Maximum live and self-weight load applied on each ramp

	Live load [kPa]	Self-weight load [kPa]
East ramp start	41.3	134
West Ramp	46.6	124
Festival Ramp	58.8	96

The LTP structure consists of planar uniaxial high-tenacity geogrids available in various grades.
The geogrid material reduction factors and creep factors are taken from BBA Certificate and are summarized in Table 2.

Table 2. Geogrid Reduction Factors used in the Ultimate Limit State (ULS) design.

Reduction factor: manufacturing	f_{m11}	1.00
Reduction factor: extrapolation of test data	f_{m12}	1.00
Reduction factor: installation damage	f_{m21}	1.03
Reduction factor: environmental	f_{m22}	1.17
Reduction factor for ramifications of failure	f_n	1.10
Reduction factor creep	f_{cr}	1.39
Overall reduction factor		1.84

Since the height of the embankment changes along the wall ramp, the following design steps were considered:

- Selection of the most critical section of the embankment for each line (East, Festival and West);
- Selection of a number of chainages throughout the length of each section;
- Check for criticality of embankment at lowest height;
- Definition of the minimum reinforcement requirements for each design case;
- Assessment of the average height of the embankment over the anchorage length;
- Determination of anchorage length for each case;

The design was carried out in accordance with BS EN 8006-1:2010 by using a proprietary software. Two layers of geogrids were needed to verify the design calculations. The geogrids are laid on top of the VCC piles both in longitudinal and transversal directions as described in Table 3. The geogrid grade used in the transversal direction is higher than the longitudinal direction in order to resist against lateral sliding.

Table 3 – LTP Design Output

Chainage	Transverse anchor length (m)	Longitudinal anchor length (m)	Geogrid grade	
			Transverse [kN/m]	Longitudinal [kN/m]
East Ramp (start of wall)	5.7	1.5	500	250
East Ramp (end of LTP/VCC area)	5.2	2.7	350	350
Festival Line (start of wall)	6.6	3.6	350	350
Festival Line (End of LTP/VCC area)	3.9	2.0	350	350
West Ramp (end of LTP/VCC area)	4.0	1.0	400	250

Geogrid reinforcements were installed on both the transversal and longitudinal directions as shown in Figure 1. Thanks to the high adhesion of the coating of the geogrid, the two layers of reinforcements were placed one in contact with the other without the need of an intermediate layer of soil. after the The geogrids are then covered with soil (Figure 2).

Figure 1. LTP geogrid placing

Figure 2. Soil placing on top of geogrids

5. REINFORCED SOIL WALLS

The design of reinforced soil walls was carried out for a design life of 120 years in accordance with the Network Rail design criteria.

The chosen wall system is comprised of precast concrete facing panels with a standard square shape (1.50 m wide x 1.50 m tall) that have minimum thickness of concrete equal to 14 cm. Each panel is provided with galvanized steel attachment loops cast into the concrete and galvanized steel toggle bars (minimum diameter 25 mm), which span between attachment loops. The connections are specifically designed to mechanically connect the geostrips with the panels. The geostrip free end is pulled towards the panels and pushed upwards through the first connecting point that is partially encased into the concrete (Figure 3).

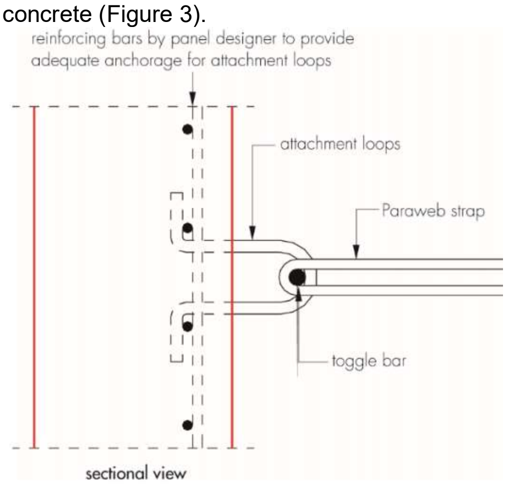

Figure 3. Connection of geostrip with panel

Thanks to the possibility of using precast customized top panels, the system was designed to match the variable project elevation along the ramps. At the end of the construction, a coping beam element was installed to fit the top wall edges. The Festival ramp was designed as a 5.80 m wide back-to-back ramp (Figure 4) to fit the tight right of way. In this case every layer of reinforcement connects both sides of the facing (tied back-to-back system) forming an unyielding structure and it allows for saving on quantities of reinforcement used.

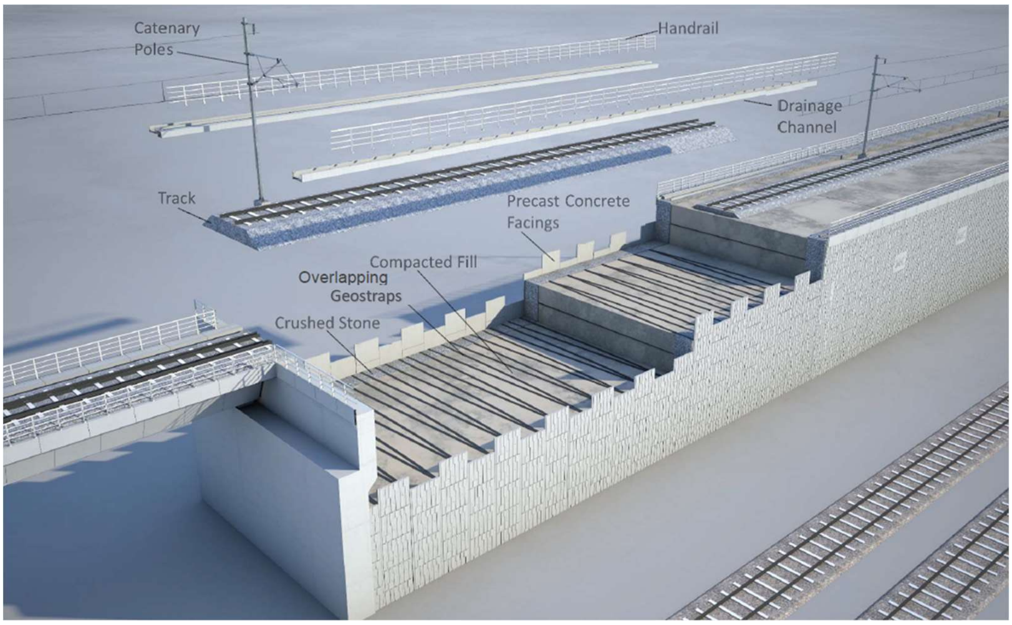

Figure 4. Back-to-back wall typical section.

5.1 System characteristics

In an MSE wall, the interaction between backfill material and reinforcement play the most significant role in the design and affects the performances of the MSE wall. The reinforced fill must be reasonably free from organic or other deleterious materials and should conform to the project requirement. The reinforced soil used was classified as granular fill, class 6I / 6J fill in accordance with TII Specification for road works Serie 600- Earthworks. The laboratory test were carried out, defining a soil friction angle equal to 38° and unit weight equal to 20kN/m^3.
The soil reinforcing strips, which are the key structural component of the system, are made of a core of high tenacity polyester yarn tendons encased in a durable linear low-density polyethylene (LLDPE) sheath.
The geostrips reduction factors, mechanical properties and creep data are taken from the British Board of Agrément (BBA) 12/H191 certificate of the product. A BBA certificate is an authoritative document proving the fitness for the purpose of a construction product and its compliance with the UK Building Regulations.
The reinforcement values used in the design are presented in Table 4.

Table 4. Geostrip Partial Factors used in Ultimate Limit State (ULS) design

Geostrip grade	Overall Factor Applied to: (fm x fn)		Design Strength- Td per strap (kN)	
	(ULS)	(SLS)	ULS	SLS
MD 54	1.85	2.31	29.21	24.67
2D 40	1.95	2.31	20.66	18.67

Ultimate Limit State values are used in Case A and B for design of reinforced soil walls in accordance with BS8006. Serviceability limit State (SLS) values are used in Case C in accordance with BS8006 and are a check for serviceability which is governed by the percentage of strain allowed for the reinforcement. The reason of limiting strain values is related to the fact that post construction movements are generally avoided by good construction practices. In this case, a strain equal to 0.5% was considered in accordance with the specified limit prescribed in BS 8006-1-2010 Table 19.

The surcharge loads used in the reinforced soil design were based on project specification. The application of the loads is in accordance with the loading of reinforced soil walls as given in Clauses 6.2.2.2 and 6.2.2.3 of BS EN 8006-1:2010. Table 5 summarizes the maximum design load.

Table 5. Live loads for Retaining Wall Design

Loads	Load Type	Design Situation			Application in reinforced soil design
		1	2	3	
Robust kerb load (2m wide)	Strip	10kPa	98kPa over 1.8m	165Pa over 1.5m	Strip load with 10kPa reduction to account for UDL from other areas
Track load (on top of Wall) (2.6m wide)	Strip	50kPa	37kPa	37kPa	Strip load with 10kPa reduction to account for UDL from other areas
Track load (behind wall) (2.6m wide)	Strip	50kPa	50kPa	50kPa	Applied as an equivalent UDL from the back of the wall
Other Areas	UDL	10kPa	10kPa	10kPa	Applied as UDL across whole embankment
Horizontal Pressure	UDL on rear face of panel	-	10kPa	10kPa	Applies a horizontal force on strap layer in accordance with spacing of reinforcement

The analysis was carried out by checking the internal stability of the structure in accordance with BS EN 8006-1:2010. The number of tie points is calculated upon the result of internal stability. The possible number of connections over two panels can vary from 4 – 8. The global and the external stability is governed by the ground stabilization system designed to support the maximum loads for the MSE wall and superstructure.
For analysis purposes, the mechanical height of the wall was taken as the height from the base of the wall to the underside of the kerb and the kerb and ballast taken as an equivalent uniformly distributed dead load.
For each ramp, the design of the tallest section was performed. Figure 5 and Figure 6 shown typical cross sections for West ramp and back to back Festival ramp.

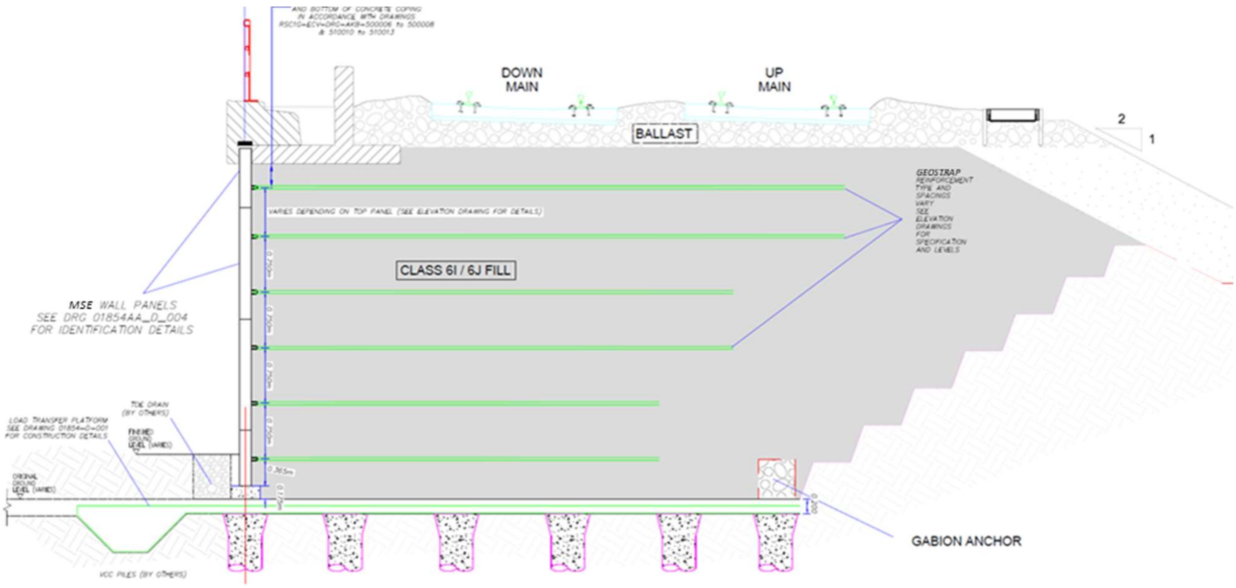

Figure 5. West ramp typical section

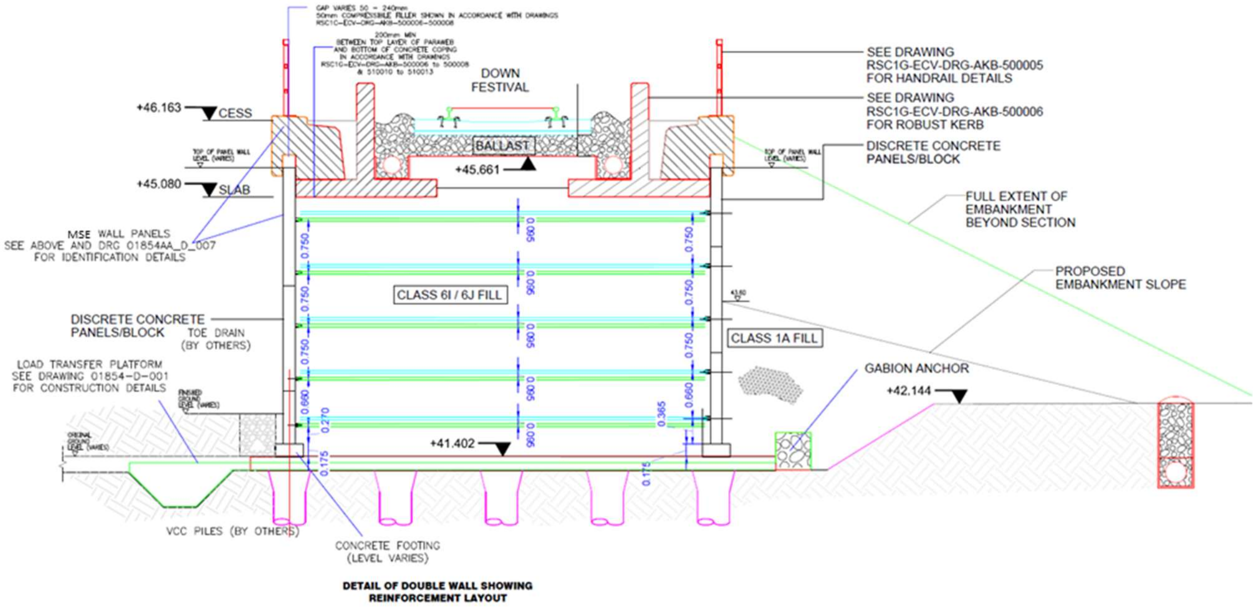

Figure 6. Festival ramp typical cross section

6. INSTALLATION PROCEDURE

The installation of ramps started with the preparation of the foundation soil and the installation of the Load Transfer Platform with geogrids. The geogrid rolls were unwound over a flat soil ensuring no slack and undulations. Reinforcements were placed in crossed directions as per design requirements. At the end of the unrolling phase, the geogrids were covered by 20 cm of covering soil. The installation of the MSE ramps was done after the completion of the LTP installation.
A smooth levelling pad was created for a proper horizontal alignment of the panel's base. Each panel was positioned with a lifting tool and held in place using timber clamps and posts. The posts were removed only after filling and compaction of the soil layer.
The strips were installed flat and the slack removed, while creating a V-shape configuration. The V-shape configuration is created by wrapping the reinforcements strip around virtual connections made by two vertical steel bars and one horizontal bar.

A different strip configuration was created for the back-to-back ramp (Figure 7). For each layer, the free end of the geostrips were pulled from one side of the panel towards the back of the opposite panel and passed through the tie point in order to form a knitted structure without any adherence issues.

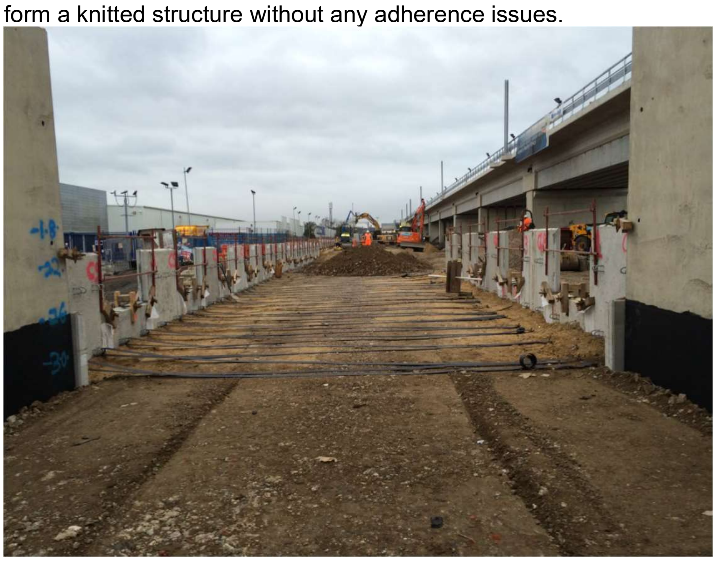

Figure 7. Festival ramp during construction

Figure 8. West ramp during the construction

After the geostrip installation, the embankment formation was built by placing 33 cm of compacted backfill soil above the strips. The backfill was spread in layers and properly compacted to meet at least to 95% of Proctor standard. The installation steps were sequentially repeated till the end of the structure. Figure 8 shown a picture of West ramp during the embankment creation and Figure 9 shown an aerial view of the completed MSE structure with railway in operation.

Figure 9. Aerial view of completed MSE structure

7. CONCLUSION

The new viaduct superstructure was officially inaugurated by Queen Elizabeth II on 17th July 2014. The massive structure took 30 weeks to complete and concluded a four-year project which was part of an overall Reading scheme valued at £895 million. £45 million was invested in the construction of a new viaduct. The three ramps, with different geometric

configurations, have variable heights ranging from 4.8 m to 7m. The project includes 2,600m^2 of MSE wall and 17,000 m^2 of high tensile geogrid for the Load Transfer Platform solution.
The East and West ramp has the MSE structure on one side only and a 1:2 slope on the other side. The Festival ramp consists of a 450 m^2 back-to-back ramp adjacent to the existing viaduct.
The use of a back-to-back configuration allow for a huge saving on quantities of reinforcement and material supplied on the jobsite.
Most of the work took place without interfering in the day-by-day rail operations ensuring the daily rail traffic through the Reading hub.

8. REFERENCES

BS8006-2010. “Code of practice for strengthened/reinforced soil and other fills”.

BBA Certificate n.03/4065, (2011). Linear Composites soil reinforcement products, Paralink Geocomposites.

BBA Certificate n.12/H191, (2012). Linear Composites Retaining Walls and Bridge Abutment Systems, Paraweb straps.

TII Publications, (2013). Specification for Road Works Series 600 – Earthworks.