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MSE retaining structure with cement-stabilized backfill and tilted facing panels: design considerations and installation procedure

Structure en sol renforcé avec un remblai stabilisé au ciment et des panneaux de façade inclinés : considérations relatives au dimensionnement et procédure d'installation

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ABSTRACT: The “Brug van den Azijn” (Bridge of Vinegar) project is located across the Albert Canal in the city of Antwerp (Belgium). The demolition and the successive reconstruction of the bridge was part of a major modernization and widening of the Albert Canal. The bridge has a 123m total span and high retaining walls that serve as ramps, on both sides. The ramps include walkways and bike paths.
The MSE wall structure presented in this paper is a reinforced soil system comprised of precast concrete facing panels and discrete high adherence polymeric soil reinforcing strips placed in a cement stabilized backfill in alternated layers. The friction developed between the soil and the reinforcements significantly improves the soil strength so that the reinforced soil mass can maintain the active wedge in equilibrium and resist to the total active earth force. For this reason, the most important design inputs are the structural filling material (friction angle, cohesion and specific weight), and the soil reinforcing elements.
On site testing has been conducted to evaluate the soil parameter after compaction and polymeric reinforcements installation. The MSE walls design procedure according with Eurocodes and BS 8006-1:2010 and the technical reinforcements behaviour in moderate aggressive environments are described in the paper. The MSE wall facing presents a tilt of 15degrees from the vertical. The installation procedure is illustrated in detail.

Keywords: Geostrips; Polymeric strips; Battered MSE wall; Mur à fruit; Cement Stabilization.

1 INTRODUCTION

Mechanically Stabilized Earth (MSE) retaining walls reinforced with polymeric geostrips are becoming an effective alternative solution to steel reinforcements. The advantageous geostrips mechanical properties are nowadays recognized by several international authorities and these structures are widely used in civil engineering applications.

The “Brug van den Azijn” (Bridge of Vinegar) project is part of the Flemish Waterways Authority plans to enlarge the Antwerp canals section, increasing the river transport capacity. The new structure included the construction of two MSE ramps, cycle paths and concrete panels cladding surfaces for covering the bridge abutments. The MSE walls facing was tilted to fit the aesthetic requirements and enhancement of the backfill material was required due to the silty sand soil available on site. This paper presents the design, peculiarities and installation procedure of the MSE wall system chosen for the project.

2 BACKGROUND

Every year, the equivalent of 2 million trucks are transported across the Albert Canal, the most important waterway in Flanders. Of the 62 bridges on the river, 31 were already widen (or replaced) and 14 projects are currently ongoing. The limited clearance height of the bridge of Vinegar was creating a bottleneck for the inland navigation.

De Vlaamse Waterweg (Flemish Waterway Autority) invested more than 15 million Euros on the construction of the new Burgemeester Eduard Waghemansbrug, better known as Brug van den Azijn. 12.5 million were dedicated to the bridge construction while 2.5 million for the widening of the N130 between the district of Merksem and Deurne. The joint venture Jan de Nul and Herbosch-Kiere was awarded for the bridge construction. The project included bus lanes in both direction, a one-way cycle lane, and a pedestrian path. The abutments were designed to support a 123 m span arch bridge, approximately 16 m wide. The new bridge clearance was targeted to be 9.1 m high, allowing the passage of ships with four layers of containers. The construction of the new bridge started in July 2017 and was completed, on schedule, by the end of March 2018.

3 PROJECT CONSIDERATIONS

3.1 Site Conditions

The borehole geophysical technique was used to define the site stratigraphy. The previous structure backfill was classified according to Table 2.1 of Eurocode 1 (NBN EN 1991-1-1-1 ANB:2007)

Table 1. Existing embankment material (from boreholes).

Soil Classification	γ - Soil Unit Weight [kN/m^3]	Φ – Friction Angle [°]
Loamy sand or sandy clay – very dense	20	32
Sand - dense	20	32

The recycling of the on-site material was possible only removing the coarser aggregates (D_{max} = 250mm) and foreseen a soil stabilization due to the high percentage of fines passing the 0.075 mm (No 200) sieve. Cohesion was detected but it is negligible for the retaining walls design purposes.

The core of the existing embankment was classified as moderate to lose loamy sand. Loose loamy sand was found underneath the previous layer. Furthermore, dense send was observed 6m below the structure bottom layer.

Table 2. Embankment core material and existing foundation soil (from boreholes).

Soil Classification	γ - Soil Unit Weight [kN/m^3]	Φ – Friction Angle [°]
Loamy sand – moderate to lose	-	27
Loamy sand – loose	-	25
Sand - dense	20	32

To improve the soil properties of the MSE wall structures foundation, a gravel layer 0.5 m thick was required underneath the reinforced soil structure and a 1.5 x 1.5 m grid of 0.7m diameter gravel piles was initially included in the design.

3.2 Loads and Standards

A distributed live load of 20 kPa was considered as standard traffic load on the roadway while 5 kPa were adopted as typical live load on the cycle path.

The MSE wall first calculations were done according to design combination 1 (DA1/1) and design combination 2 (DA1/2) of Eurocode 7.

3.3 Reinforced soil walls

Two 300 m long reinforced soil ramps up to 10.5 m high were designed by Maccaferri for a total of 3,850 sqm area. The system chosen is called MacRes and it is comprised of concrete facing panels and ParaWeb polymeric strips. More than 80,000 linear meters of geostrips were installed. These strips are made of high tenacity polyester yarn encased in a linear low-density polyethylene (LLDPE) sheath. The reinforcements are the key structural component of the MSE wall system and are mechanically connected to the facing panels through a specially designed connection.

If Eurocode 7 was the selected code for load, material and resistance factors, NF P 94-270 and BS 8006-2010 provisions were considered for determining the reinforcement friction coefficients and structure design method. These structures are designed either with the coherent gravity method or the tie-back wedge method depending on the extensibility assumption. Full-scale studies confirm that the post-construction axial tensile strain of these geostrips is less than 1%. Therefore, based upon BS 8006:2010, the reinforcement can be classified as inextensible and the design of the structure should follow the coherent gravity method.

The geostrip used for the project calculations is ParaWeb 2D30 kN. Each panel is provided with loop type connection (called MacLoop). The number of connections is calculated based upon the results of the stability checks. The standard square panel dimensions are 1.5x1.5 m.

Table 3. Mechanical properties of the geostrip used for the project.

ParaWeb Grade		**2D30**
Ultimate tensile strength Tu	kN	30.16
Long term tensile strength Tcr (20° C)	kN	21.85
Strip width	mm	50+2

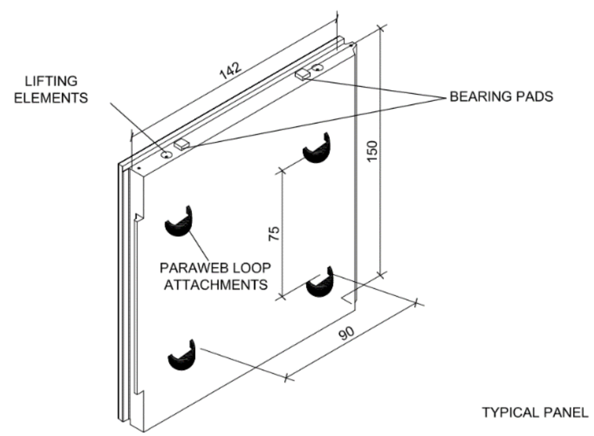

Figure 1. Selected MSE wall system typical panel.

3.4 Soil Stabilization

The internal stability of the reinforced soil structure is mainly given by the mechanical interaction between backfill and reinforcement. MSE walls performance issues are often due to low quality backfill, lack of filtration design and deformations due to poor compaction practices. The chemical stabilization is sometimes utilized to improve the load bearing capacity of the soil. The soil type and mineralogy determine the most suitable treatment. Lime and cement are the most common binders, but also fly ash and blast furnace slag are used for soil stabilization. Portland cement was chosen for this project. After the contact with water, the cement reacts, starting the hydration process. The soil tends to become harder, therefore the soil mixture should be rapidly placed and compacted. Precautionary mechanical properties of the stabilized soil were assumed for the design, however the cement treated mix reached an average value of 40° friction angle.

Table 4. Soil parameters considered in the MSE wall design.

Soil Type	Φ Friction Angle [°]	c Cohesion [kPa]	γ Soil Unit Weight [kN/m³]
Reinforced soil	32	0	18
Retained soil	26	0	18
Foundation	40	0	18

3.5 Façade design

The architects of the project designed an articulated façade for the bridge structures. Therefore, the reinforced soil walls and the true abutments were designed with a 75° inclination. The MSE walls calculations were performed according to NF P 94-270 provisions for “murs à fruit”. The loop connections were slightly inclined to keep them horizontal compared to the soil layers. Several stability checks were performed due to the unusual walls configuration.

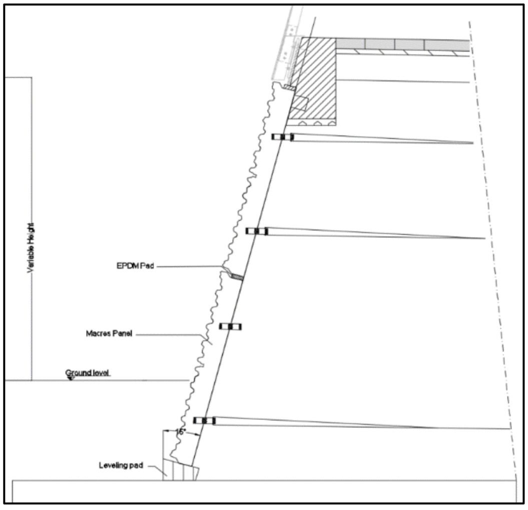

Figure 2. MSE wall typical cross section with 75° inclination.

The top panels of the reinforced structure had to perfectly match the wall elevation, without using a proper coping beam to hide the elevation step. Each top panel was specifically designed to meet the project geometry.

Figure 3. Cut top panels according to architects' requirements

A granite type of aesthetical pattern for the concrete panels was required by the project contract documents. The texture was realized by means of a polymeric 40 mm matrix placed at the bottom of the concrete panel mould. The panels structural thickness is 0.14 m, but the maximum thickness is approximately 0.18 m due to the form liner section.

The client requested 0.75 m high panels, therefore a horizontal fake joint was included in the form liner. The fake joint was meant to be aligned to the real horizontal joint between two consecutive panels. The precise alignment was possible thanks to AutoCad modelling based upon precise topographic measurements.

The panels were poured in anthracite colour and a wash-out treatment of the front face was done after appropriate aging of the concrete to show the black basalt aggregates.

No corner elements were casted for this project. Acute or obtuse corners were just creating simply approaching two consecutive panels.

Figure 4. Fake and true horizontal joint alignment.

3.6 Cladding elements

The bridge of Vinegar abutments were smooth grey concrete structures. More than 1,820 sqm of cladding panels were manufactured to cover these structures and provide the same aesthetical finishing adopted for the soil reinforced structures. The panel-to-abutment connection system was designed to connect the panels without using geostrips and was covered by the adjacent panel. The solution had to be technically resistant and easy to install. Inox plates and nails were used to meet the project durability requirements.

4 SYSTEM INSTALLATION

The installation of the reinforced soil structure was performed by experienced installers and was completed in 4 months.

The retaining walls are characterized by slight curvatures and 75° inclination.

A smooth levelling pad was essential for proper inclined and horizontal alignment of the panels. Each panel was positioned with a lifting kit and held in place using timber clamps and posts. The posts were removed only after filling and compaction of the soil layer up to half of the supported panel.

The strips were installed flat and the slack removed, while creating a V-shape configuration.

The reinforcements were occasionally bent to meet the project geometry.

The backfill was spread in layers and properly compacted to meet at least to 95% of Proctor standard.

The cladding panels were bolt to the abutments and aligned with the existing soil reinforced structures.

Figure 5. ParaWeb strips installation.

Figure 6. Soil placement and compaction.

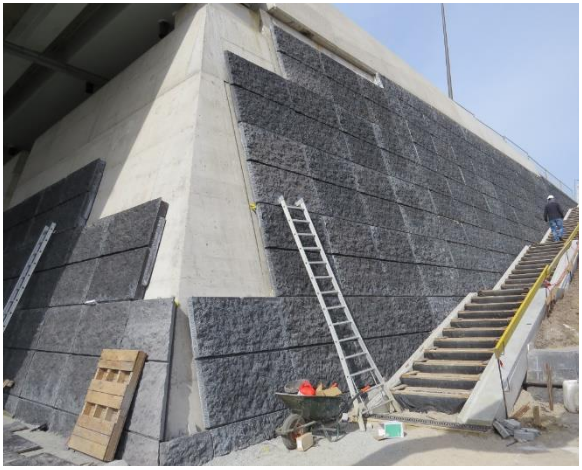

Figure 7. Retaining walls completed, cladding installation.

Figure 8. Cladding completed after the bridge placement.

Figure 9. Brug van den Azinj in April 2018

5 CONCLUSIONS

The new steel arch bridge was finally inaugurated on April the 2nd 2018, after 9 months from the beginning of the construction. 15 million Euro were invested in the structure modernization. The bridge clearance was raised from 6.85 m to 9.10m to increase the inland navigation. The project included 3.850 sqm of MacRes MSE wall system and 1.820 sqm of cladding surfaces: Two ramps 300m long each side, up to 10,5m high were designed meeting challenging aesthetical requirements. The new bridge, serving both the largest industrial estate of the Antwerp province and the nearby residential neighbourhood, relief the traffic load increasing the people quality of life.

6 ACKNOWLEDGEMENTS

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