Reinforcement of an old retaining structure using soil containing fine particles and multifunctional geocomposite

Alain Nancey & Anna Le Faouder

TenCate Geosynthetics France, France

ABSTRACT: For the construction of new retaining structure, geosynthetics are often proposed with a facing system chosen by the site owner to fit with stability but also aesthetic requirements. Their use for the reinforcement of existing structures can be also of great interest when the existing facing shall be preserved but cannot be insured the stability itself alone. An old access ramp to a bridge submitted to an intensive traffic was damaged when a waterpipe leakage induced a loss of the bearing capacity and large settlements at the surface level. Geosynthetics were preferred to other solutions to repair the structure for practical and economic reasons.

Keywords: reinforcement, retaining wall, silty soil

1 INTRODUCTION

At the end of January 2014, a leak of a water pipe provoked a subsidence of the roadway on the north access ramp to a bridge crossing the Seine river in the west of Paris. This forced to the reduction by half of the road width, impacting a daily traffic of 43,000 vehicles. The repair of the structure had to face two major issues. The first was linked to the poor quality of the subsoil with a high risk of settlements and existing water pipes. The second was the need to keep in place the existing concrete wall to limit the time and work extent. However, a simple refurbishment was not sufficient to guaranty that the concrete wall would be able to support the loads of a growing traffic. It was decided to build a reinforced embankment avoiding any horizontal pressure on the concrete structure. A flexible solution was also considered better to absorb any differential settlement due to the poor subgrade. To limit the cost, the fill material used for the embankment was a silty soil from the site. The use of a geocomposite able to reinforce and dissipate the pore pressure allowed a good compaction of the fill, thus reducing the risk of further deformation and insuring the stability of the ramp. The earthworks were realized in August 2016 and re-opening of the full road width was possible end of 2016.

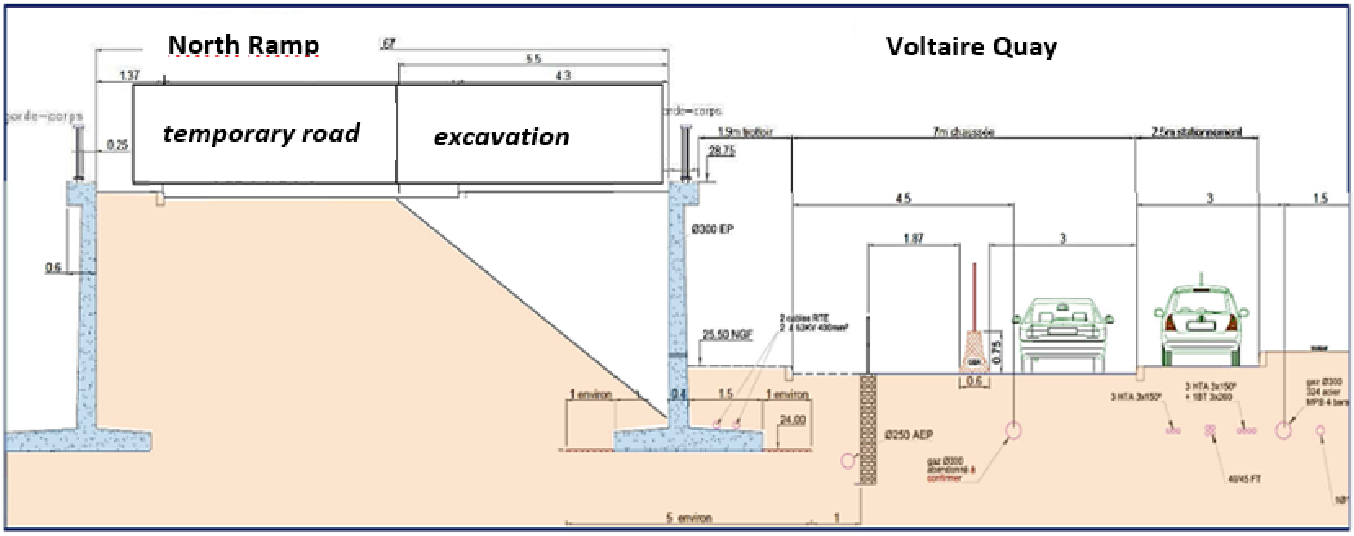

Figure 1. Typical cross section during the temporary phase before reinforcement.

1.1 *Description of the structure and geotechnical context*

The access ramp is a road embankment 100 m long, confined between two concrete walls (Figure 1) based on a shallow foundation. The maximal height of the embankment reaches 5.4m at the bridge level. The ramp is separated from the bridge by an expansion joint.

The surveys and tests carried out on the site have highlighted successive pavement layers and embankment fill having low compacity at the rear and under the retaining wall. Heterogeneous brown sandy materials have been encountered from the top of the ramp platform to approximately 6.5 to 9 m deep. The technical embankments confined between the walls of the ramp, can be differentiate from those, older, seen under the walls foundation and realized at an earlier time. A subbase layer covers the upper part of embankments. Bituminous materials, whose thickness reaches nearly 30 centimeters are observed on top, testifying to probable successive recharges to compensate for settlements of the embankment which have developed regularly since the construction. Below 6m deep, alluvial sand, with a thickness of 7/8 m can be dissociated into two parts. A first layer, from 4 to 5m thick and considered to be normally consolidated, is made of gravel and brown gray silty sand. A lower layer about 3 m thick, constituted of a grayish shell-like sand, with a very low compacity contributes to explain the disorders observed on the structure since its construction.

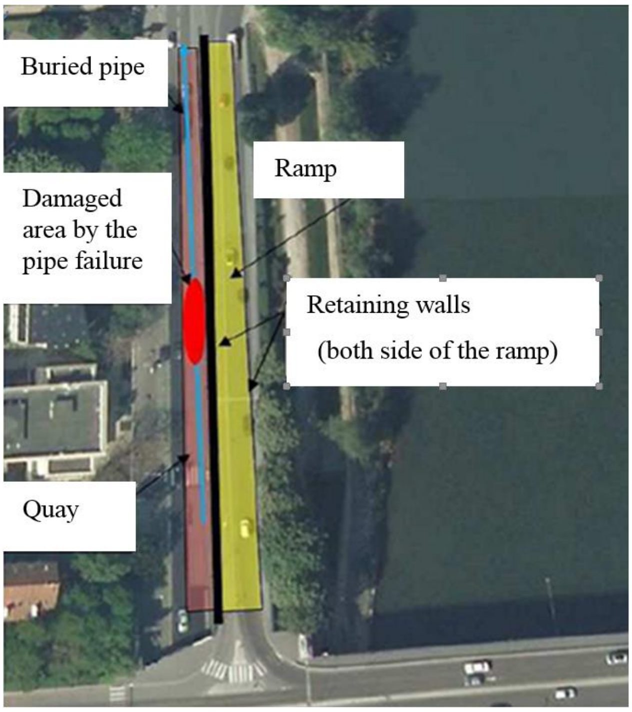

Figure 2. top view from the ramp and the bridge.

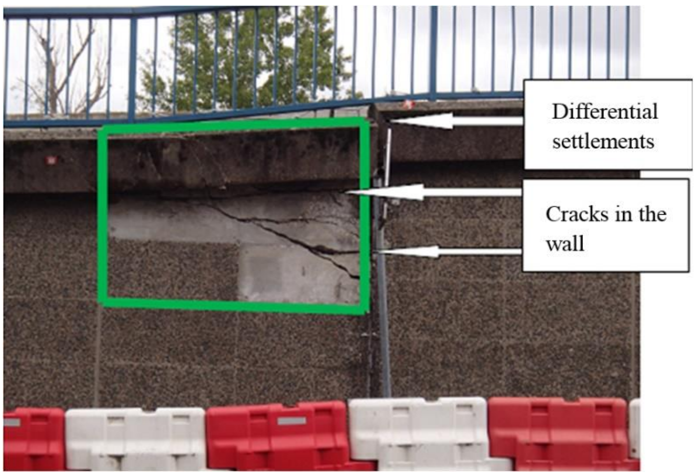

Figure 3. damages on the wall.

1.2 *Disorders analysis*

The first sign of damage was a pavement subsidence, subsequently revealing a leak of a buried water pipe beneath the “Voltaire “quay, situated along the ramp on the side opposite to the river (Figure 2). Further investigations show disorders partly hidden by the facings of the wall of the reinforced concrete wall. Alignment breaks have also been noticed on the equipment along the access ramp (guardrail, cornices ...), cracks in roadways, transverse and horizontal offsets on the facing of the retaining walls.

Due to the damages (Figure 3) seen on the retaining wall separating the ramp from the quay, it was decided to remove the earth pressure applied on the wall by an excavation. Consequently, the traffic was limited on one part of the ramp until the full reinforcement of the structure.

The water leakage contributed to settlements by washing the fine particles from the ground and reducing the bearing capacity of the wall foundations. This provoked the tilting of the wall against the adjacent wall section that shall support loads normally carried out by the foundation. This overloading may disturb the general equilibrium of the wall and induce further displacements and deformation.

2 GEOSYNTHETIC SOLUTION

2.1 *The choice of the solution*

To limit the load carried out by the concrete retaining wall, the solution chosen was to rebuild a self-standing reinforced embankment overall the 100m length ramp. A geosynthetic layer is installed at the base of each 50-cm fill layer on a vertical profile and are oriented in the perpendicular direction of the road. It covers all the width of the embankment. On each side the geosynthetic layers are wrapped around, confining totally the fill material and avoiding any earth pressure on the existing and remaining masonry. By consequence, the concrete walls are not a retaining structure any more but become just a component of the facing.

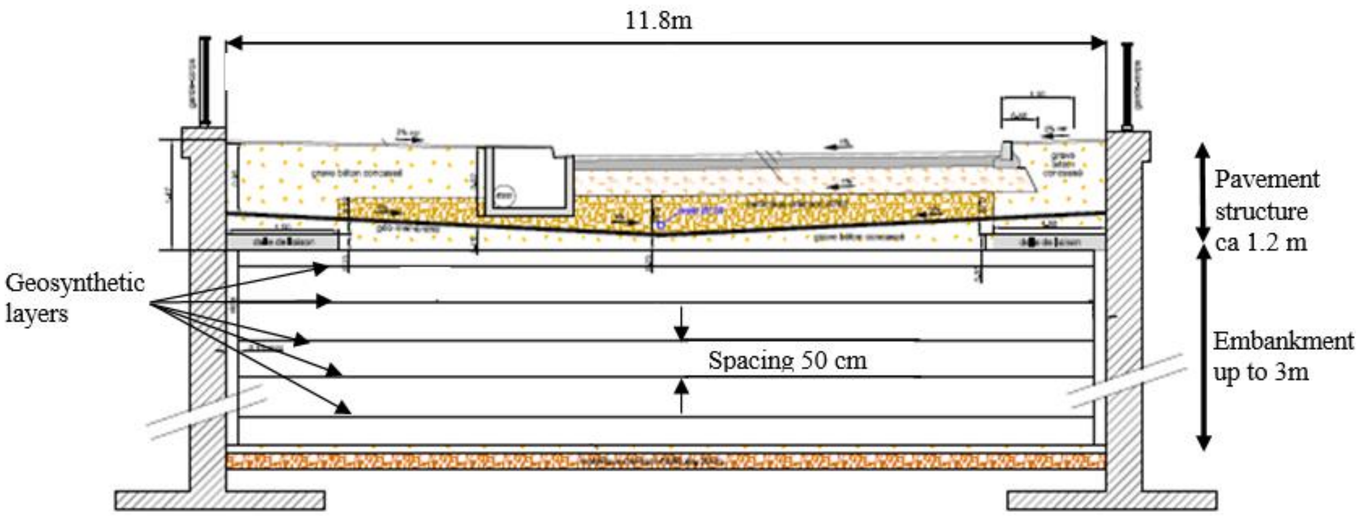

Figure 4. Typical reinforced cross section.

2.2 *Fill material*

To minimize the impact of the earthworks on the surrounding traffic, most of the materials on site were reused as fill material. This reduced also strongly the cost and the environmental impact compared to a solution where the material from the site shall be removed and replaced by a better granular material from a quarry. Samples were excavated from the old embankment and studied to check their mechanical and hydric properties.

Table 1. characteristics of the fill material taken from the site.

		Natural moisture content	Optimum proctor density	Optimum proctor moisture content	w_n / w_{opn}	Friction angle
	symbol	w_n	γ_d	w_{opn}		ϕ
	unit	%	kN/m^3	%	%	°
Light brown clayey gravel	Sample P1	4.1	19.2	7.8	50%	25
	Sample P2	5.1	19.6	9.5	50%	25

Table 1 shows characteristics of the material that were important during the conception. The difference between the natural moisture content and at the optimum proctor shows that the material is very dry and very sensitive to the water content. During installation, if the material is very dry, the water content should be adjusted by watering. At the contrary, if very humid, it will not be possible to compact it. The use of a composite geotextile providing the reinforcement function, but also having suitable hydraulic properties, allows the reduction of the pore pressure that occurs during compaction and ease the control of the water content. The proportion of fine particles and moisture content may have an important effect on the friction within the material.

Grain size distribution of the different samples are reported on Figure 5 showing also limits defining frictional fills and fine-grained fills (Lawson 2005). This light brown clayey gravel seen on figure 6 and taken from the old embankment, is exactly in the overlap zone between frictional and fine-grained fills confirming that this material could be frictional and moisture sensitive. That means that it was possible to use it as a fill material on this site but taking care of the water content during installation and compaction of the material.

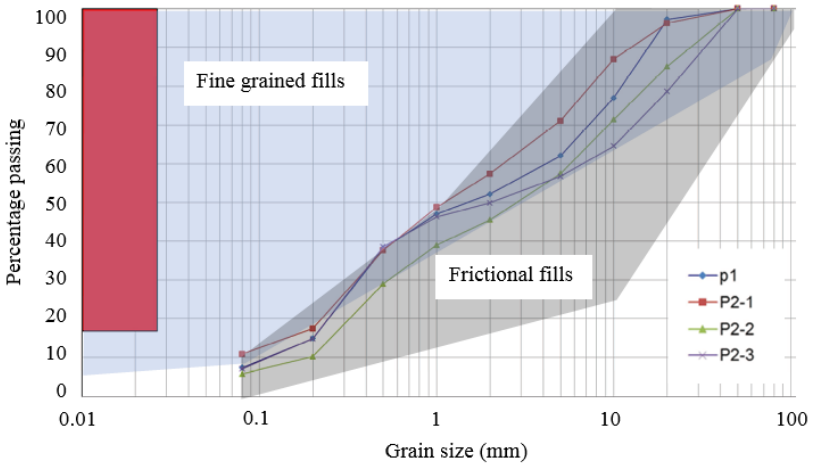

Figure 5. grain size distribution and typical grading envelopes for frictional and fine-grained fills.

Figure 6. fill material on site.

2.3 *Geosynthetics*

Reinforcement of retaining wall or steeped slopes are generally realized by using geogrids expecting higher interaction with granular materials compared to other geosynthetics. Interaction is governed by two possible phenomena: the direct friction of the soil particles with the product and the so-called interlocking that corresponds to the insertion of gravels into the geogrid mesh. But this interlocking occurs only if the size of the granular material fits with the mesh size of the geogrid. With fined grained soil, the interaction is mainly given by friction and other geosynthetic than geogrids can be used such as woven or composite. Moreover, in case of the use of residual soil with high water content, composite geosynthetic combining reinforcement and drainage capacity may show a better interaction behavior than geogrid.

Loke and al 2002 noticed a reduction in pull out resistance of 20% only with the nonwoven composite when the reduction in soil strength was more than 70% under fully saturated conditions. Compared to geogrid, the composite geotextile has shown a quicker pore pressure dissipation (figure 7) giving a higher shear resistance at the geosynthetic-soil interface.

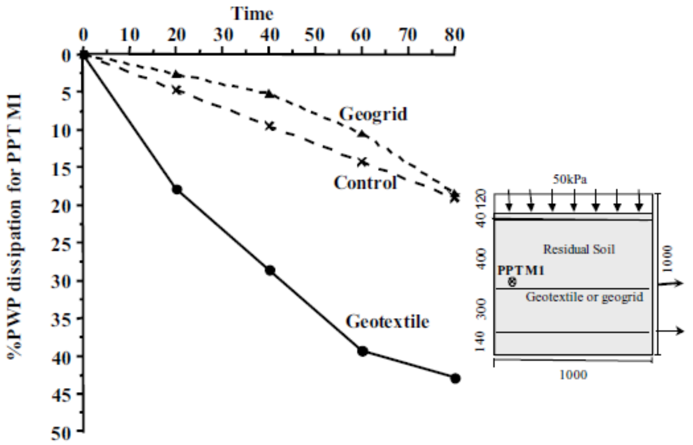

Figure 7. Pore water pressure dissipation at 1 m from the facing. (Loke and al 2002)

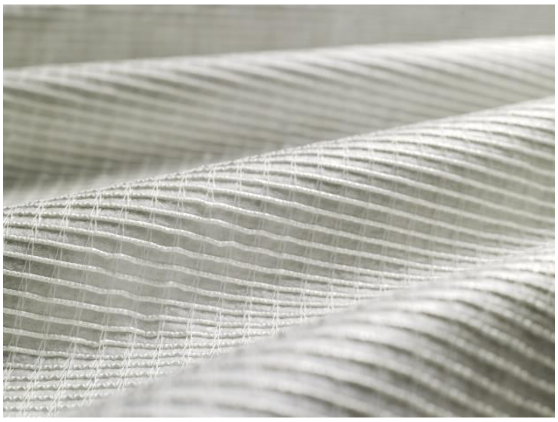

Figure 8. reinforcement geosynthetic

Because of the type of fill described above, the consultant chose a high strength geocomposite made of multi-filaments polyester yarns stitched on a continuous filaments nonwoven (figure 8). During compaction of the fill, the nonwoven allows the reduction of the pore pressure and provides a protection of the high strength yarns insuring the reinforcement function.

3 DESIGN

The structure checked in the design, consists of a 3m thick reinforced fill in the critical cross section with 6 layers of geosynthetic. The 1.5m of material on top is taken as a permanent load of 30 kPa and a traffic load of 13 kPa was considered. A friction angle of 25° was taken for the fill material. The study was carried out with ReSSA(3.0) software following a calculation at failure. The compound stability, including deep seated failure is checked for slip circle using the Bishop method, as shown on figure 9. following the Eurocode 7 approach 3, partial factors seen on table 2, are taken on actions and materials. An overall safety coefficient of Fs> 1 is required to insure the stability.

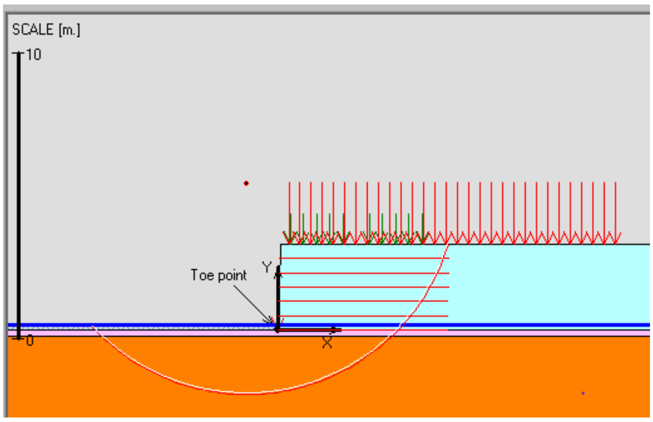

Figure 9. critical slip circle showing the minimum required factor of safety.

Table 2. Partial safety factors.

Action	permanent	temporary
	γ_{Gsup}=1.35	γ_{Qsup} =1.5
Material		
weight	γ_g =1	
Friction angle	$\gamma_{\varnothing'}$ =1.25	
Shear strength (cohesion)	$\gamma_{C'}$ =1.25	
Direct sliding/ pull out	$\gamma_{M;f}$=1.1	
Geosynthetic strength	$\gamma_{M;t}$ =1.25	

Considering all these partial factors, a geosynthetic reinforcement having an ultimate tensile strength of 125kN/m provides the justification of the stability.

4 INSTALLATION

The reinforcement was installed with a classical wrap around method (figure 9) and a vertical spacing of 50 cm. EPS blocks have been used as a formwork between the reinforced embankment and the concrete structure, as shown on figure 10. This allows a good compaction of the fill (figure11) on the whole area. The EPS blocks were removed after the completion of each compacted layer and placed upward for the following layer, creating a space between reinforced soil and the old retaining wall. The old masonry was then protected from any horizontal pressure coming from the embankment.

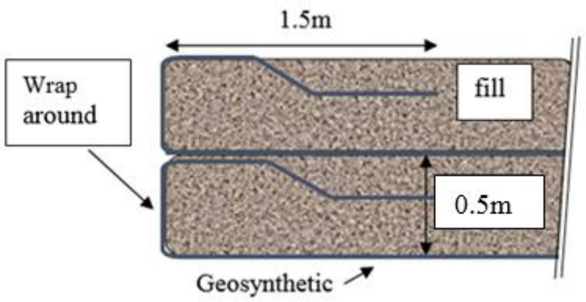

Figure 9. Schematic cross section of a reinforced layer.

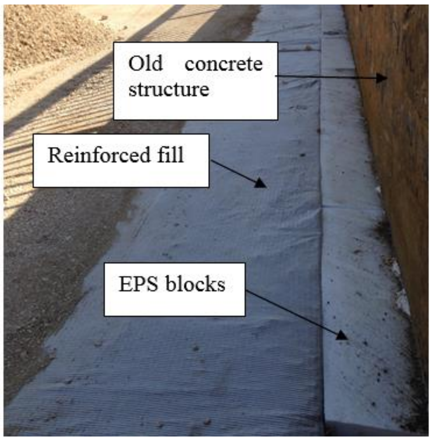

Figure 10. Junction between old concrete structure and reinforced fill

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Figure 11. compacted layer before paved structure installation.

5 CONCLUSION

The ramp reopened at the end of 2016, after the completion of the rehabilitation works, but during this phase it took less than 1 month to reinforce the embankment using geosynthetics. The use of a geocomposite combining reinforcement and water pressure absorption made easier the use of the fine-grained material taken from the site. The reinforced embankment was built to avoid any horizontal pressure on the existing concrete masonry that was partially damaged by the subsidence. Finally, this solution avoids expensive solutions like piling that were studied initially.

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