SEGMENTAL RETAINING WALLS USING LIME STABILISED SOILS IN THE NEW VENICE BYPASS (ITALY)

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Abstract: The new Venice Bypass is designed to attract traffic away from the existing, overcrowded Mestre City highway.

In the stretch of the highway around the new Preganziol junction, concrete retaining walls were specified on both sides of the road. As a result of the presence, in this area, of soft foundation soil, a proposal was made to adopt a flexible retaining wall system, in order to avoid the need for expensive piled foundations under a rigid structure.

As part of the design brief, the environmental impact requirements specified two particular conditions for these structures; they were to be concrete faced and the facing was to be a natural grey finish.

As a consequence of the lack of locally available granular backfill material, the road embankment was to be constructed using lime stabilised soils. This resulted in an alkaline fill material (pH >12) which would have to be incorporated into any alternative design proposals.

Keywords: alkalinity, bridge approach, geogrid reinforcement, polyvinyl alcohol, reinforced clay, segmental retaining wall

INTRODUCTION

The A4 Italian Highway crosses all the northern Italian region and it goes from Turin (in the North-West) to Trieste (in the North-East). Along that highway, in the area of Mestre (Venice), there has always been a critical point because of the heavy traffic, both local and long-range, passing in that stretch. Due to this reason since many years ago there has been the need of creating a new ring-road which bypassed Mestre City on its north side so that all the long range traffic would be attracted by this new stretch, while all the local traffic would continue to flow on the actual highway.

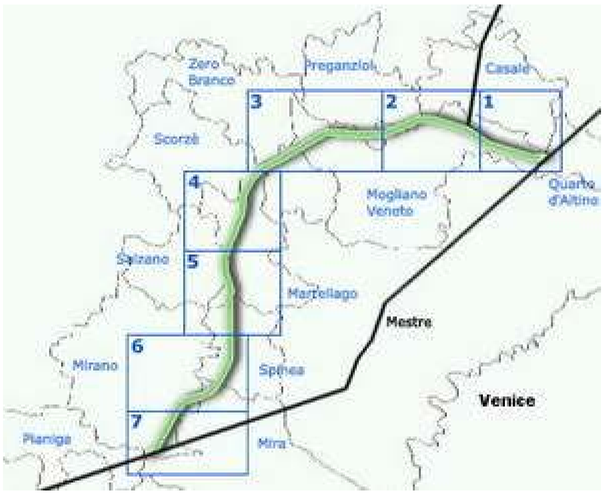

Figure 1. Overview of the Venice Bypass

The new bypass has a width of 32,5 m and a length of 32,3 km and, as can be easily seen from Figure 1, crosses eleven municipalities with the resulting problem of intersections with a number of national and local roads. For this reason the whole local traffic plan had to be revisited, because some of local roads had to be interrupted, while a number of overpasses had to be designed.

This paper deals with the design and realization issues of one of these overpasses, next to the Preganziol (Treviso) highway exit (see Figure 2) between km 25+250.00 and km 26+228.50 of the bypass.

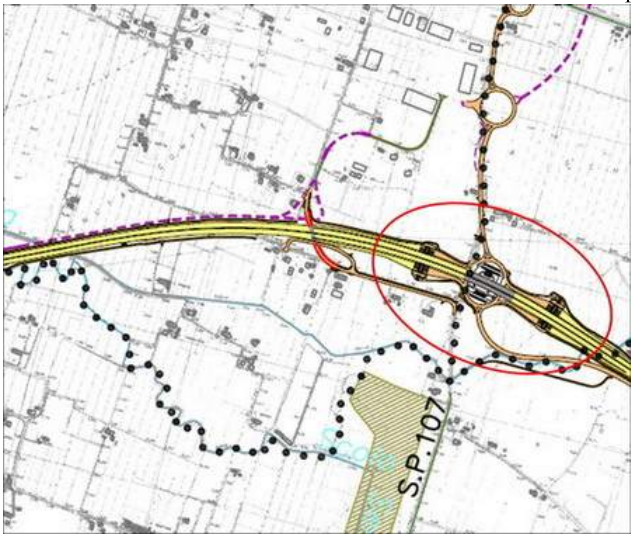

Figure 2. Overview of the Preganziol highway exit

DESIGN OF THE PREGANZIOL OVERPASS

During the design phase of the whole project, many parts of the Venice Bypass have not been completely defined; therefore, in many situations, the main contractor had then to propose solutions that had to fulfil all the technical and environmental requirements fixed by the Highways Authorities.

At both sides of the bridge ramps of the overpass next to the Preganziol highway exit, due to problems of land availability, vertical retaining walls had been specified, with prescriptions indicating only the type of material they had to be made of (concrete) and their finishing colour (grey). Each of the two ramps approaching the bridge is approximately 400 m long, with a height varying from 1,00 m to 10,20 m above ground level.

Ground conditions

When the main contractor had to deal with the design of these walls, the initial idea was to build conventional rigid reinforced concrete walls but, due to the poor geotechnical characteristics of the local soils, both in terms of resistance and deformability, there would have been the need of foundations with thick concrete slabs and deep piles, reaching the stiffer layers.

Many geotechnical tests had been performed along the new bypass, especially where new overpasses and underpasses should have been built. One of these tests, a cone penetrometer test, had been performed exactly under one of the ramps of the Preganziol overpass, and its results are reported in Figure 3.

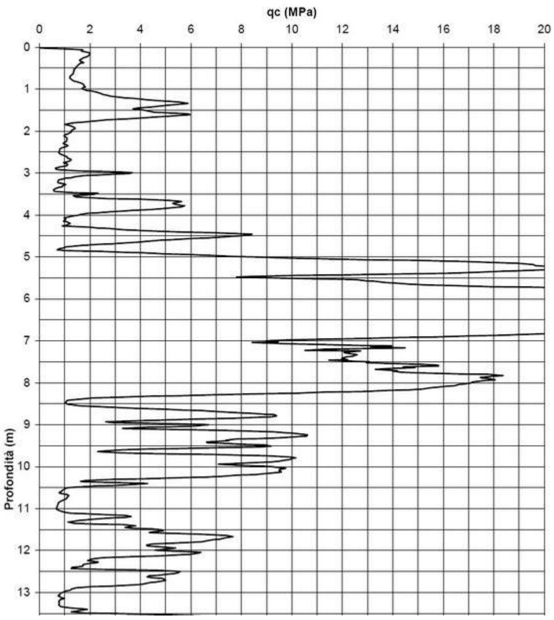

Figure 3. Results of the one of the cone penetrometer tests

The interpretation of these tests led to the definition of the soil stratigraphy, which is summarized in Table 1. Groundwater level was found at a depth varying between – 0.8 m to –1.0 m from the ground level.

Table 1. Summary of geotechnical parameters

Depth	Soil description	ϕ' (°)	c' [kN/m^3]	γ [kN/m^3]
0,0 – 4,80	Silty and slightly sandy clay	28	5	19,0
4,80 – 10,00	Medium-fine slightly silty sand	39	0	18,5
10,0 – 15,00	Clayey and slightly sandy silt	28	5	19,0
15,00 – 21,50	Medium-fine silty sand	38	0	19,0
21,50 – 31,00	Silty clay with lenses of sandy silt	28	5	19,0
31,00 – 35,00	Silty sand	39	0	19,0

Lime stabilization of cohesive soils

Another relevant issue of the design and construction of the embankment was the lack of granular soil which forced the contractor to use the local cohesive soil for the filling. This kind of soil is not normally suitable to use as a filling material for road embankments, therefore there was the need of stabilizing it with lime or cement, in order to enhance its geotechnical properties.

Figure 4. View of the lime stabilized soil

This stabilization technique usually applies to soils with a high content of clay and it consists in mixing the natural soil with calcium oxide (CaO) and the compaction of the mixture at an optimum water content (lime stabilized soil). If the natural soil has a low content of clay and a high content of sand or gravel, usually calcium oxide is substituted with cement (cement stabilized soil). In case of soils with both high contents of clay and sand, a priori it is impossible to define which would be the best additive to be used, therefore site specific tests with different mixtures have to be made. Due to the chemical properties of calcium oxide and cement, the stabilized soil therefore has alkaline properties with a pH value greater than 12.

The local soils in the area of the Preganziol that had to be used as fill material of the embankment were a sandy silty clay and a medium-fine grey silty sand. They both had been mixed with lime and tested in a laboratory in order to define their geotechnical properties. Even if the results of those tests show great improvements both in terms of friction angle and cohesion - friction angle between 35° and 39°, cohesion between 40 and 90 kPa - conservatively the adopted design values for the retaining walls were a friction angle of 32° and a cohesion of 0 kPa, in order to prevent possible heterogeneities in the measured values.

Aesthetic issues

The Venice Bypass is one of the most important Italian public works of the last decades, therefore every single aspect of it had to be carefully analysed, also from the aesthetic point of view. As reported above, the aesthetic prescription for the Preganziol overpass was the finishing colour (uniform grey) of the retaining walls; if the contractor wanted to choose a different finishing, he would have to prepare a 3D photo-realistic view of the final layout and present it to an Environmental Commission for the approval.

THE SOLUTION

When the main contractor had to prepare the final design of the Preganziol overpass he then had to deal with three main issues:

- poor geotechnical properties of the local soils
- use the local lime stabilized soil (with a pH value greater than 12) as filling material
- aesthetic approval of the solution by an Environmental Commission

The solution that the main contractor submitted to the Highway Authority for the approval were vertical segmental retaining walls reinforced with polyvinyl alcohol (PVA) woven geogrids, directly laid on the existing ground, without any deep piling foundation.

The idea of the segmental retaining walls with PVA geogrids came out from the need of

- having a flexible system which would have a much better behaviour than a rigid concrete wall founded on piles in terms of elasticity and of possible absolute and differential settlements
- good chemical behaviour also in an alkaline environment
- fulfilment of the aesthetic obligations

Stability issues

As the height of the retaining walls varied from 1,00 m to 10,20 m, the stability had been verified for a number of intermediate heights in order to optimize the total cost of the work. The structural configuration of the segmental retaining walls has also been subject to an optimization by changing the strength and the anchor length of geogrids with the wall height.

In the upper part of the walls, due to the lower levels of stress, PVA geogrids with an ultimate tensile strength of 55 kN/m have been used while in the intermediate geogrids with an UTS of 80 kN/m and in the lowest part geogrids with an UTS of 110 kN/m.

The reinforcing PVA geogrids have the characteristics shown in Table 2:

Table 2. Geogrid characteristics

Material	**Fortrac® 110 MP**	**Fortrac® 80 MP**	**Fortrac® 55 MP**
Description	Polyvinyl alcohol (PVA) woven geogrid with polymeric coating		
Ultimate tensile strength (longitudinal)	110 kN/m	80 kN/m	55 kN/m
Elongation	≤ 6 %	≤ 6 %	≤ 6 %
F_{creep}: creep reduction factor (120 yrs)	0,65	0,65	0,65
f_{m11}: reduction factor for consistency of manufacture and availability of data	1,00	1,00	1,00
f_{m12}: reduction factor for extrapolation and manufacture (120 yrs)	1,30	1,30	1,30
f_{m21}: reduction factor for mechanical damage (gravel and sand)	1,06	1,06	1,09
f_{m22}: reduction factor for environmental effects (pH ≥ 9)	1,00	1,00	1,00
LTDS: Long Term Design Strength (120 yrs)	**51,89 kN/m**	**37,74 kN/m**	**25,23 kN/m**

LTDS (long term design strength) for every material has been calculated according to the BS 8006 using the following equation:

$$LTDS = (F_{creep} \cdot P_{ult}) / (f_{m11} \cdot f_{m12} \cdot f_{m21} \cdot f_{m22})$$

All the reduction factors have been supported by certified laboratory tests because the reliability of these values has a fundamental importance in the design as they directly affect the overall safety factor of the structure.

With the isochronous curves, it is possible to obtain the variation of strain with time at different levels of stress applied to the geosynthetics, expressed as a percentage of the ultimate tensile strength (UTS). In Figure 5 the curves related to the PVA geogrids are shown. From this chart it is for example possible to see how at 50 % of the ultimate tensile strength the difference between the immediate (2,8 %) and the long term strain (4,2 %) is very low. It is therefore possible to appreciate both peculiarities of PVA geogrids: high Young modulus and low creep.

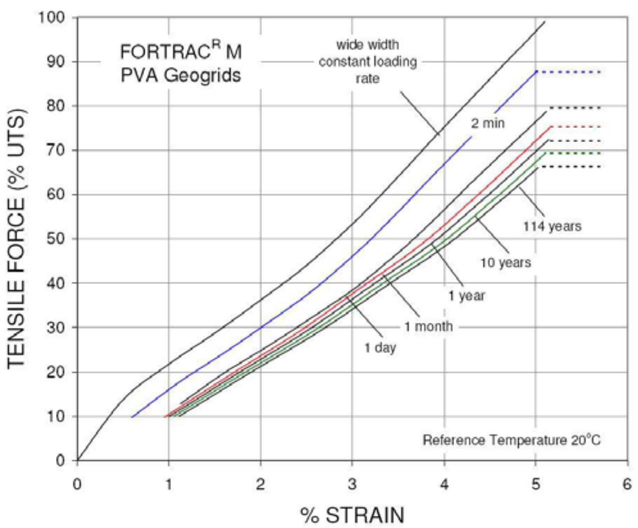

Figure 5. Isochronous stress-strain curves for the Fortrac® M PVA Product Line

Global stability of embankment has been verified with the simplified method of Bishop (1955), assuming circular potential failure surfaces. The safety factor is therefore defined as the ratio of the available shear strength (τ_f) to the shear strength (τ_m) which must be mobilized to maintain a condition of limit equilibrium.

The internal and compound stability of the segmental retaining walls has been performed analyzing both circular (Bishop) and polygonal (Modified Janbu) failure surfaces.

A special care has been taken into account when dealing with the connection between PVA geogrids and blocks because a failure of this connection, could cause the collapse of the entire structure. Due to this reason it had been possible to use a combination of PVA geogrids and concrete blocks which already had been subject to extensive certified testing in terms of pull-out resistance and break of the connection.

The connection stability has been verified for every single geogrid/block interface, following the procedure fixed by the American Federal Highway Administration (FHWA, 2001).

The vertical spacing between geogrids has been fixed in 0,60 m throughout the whole height of the walls. Some additional shorter layers have been added between the primary geogrids where there was a lack of the connection resistance and in order to prevent undesirable deformations of the facing.

In Figure 6 the geometry of a typical cross section used for the analysis is shown, where the different types of geogrids used are summarized in the table, and the geotechnical characteristics of the soils considered for the analysis are highlighted.

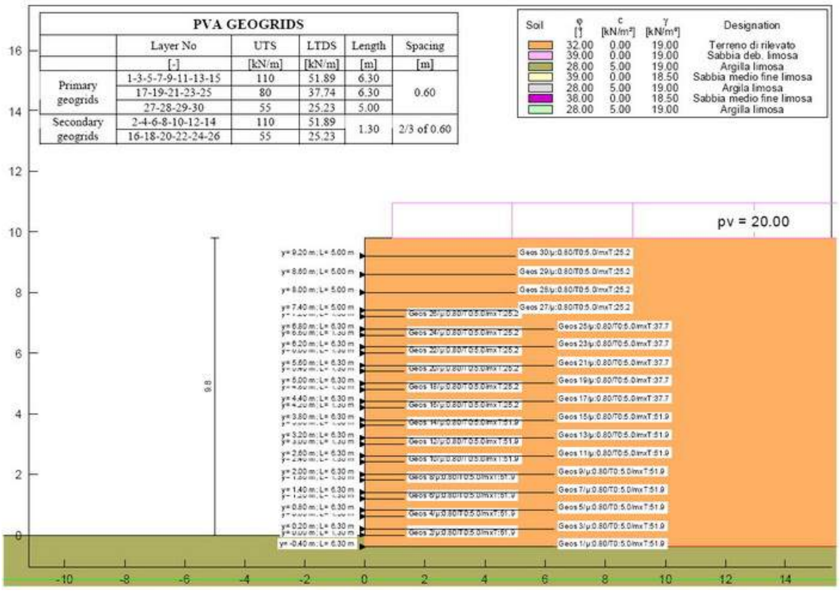

Figure 6. Cross section of the segmental retaining wall 10,2 m high

Both the seismic effect, with a horizontal acceleration of 0,04·g, and the groundwater level, at a depth of 1,0 m, had been taken into account in all the performed calculations.

The long time design strength (LTDS) of the geogrids has been taken into account in the determination of the safety factors, which had always to be greater than 1,3 as required by the current Italian standards.

In the project we are dealing with in this paper the choice of using PVA as raw material for the reinforcing geogrid has absolutely been mandatory due to deformation and chemical issues. Polyvinyl alcohol is a polymer which guarantees high Young modulus, low creep and very high chemical resistance also in alkaline environments, such as lime stabilized soils (pH > 12).

Aesthetic issues

The last step before the final acceptation of the proposed solution by the Highway Authority was the approval from the aesthetic and environmental point of view. In order to fulfil the preliminary specifications, the chosen type of segmental concrete blocks was the Rockwood Classic block in grey colour and with a straight split face.

3D photorealistic views of the whole embankment such as those of Figure 6 and 7 had been prepared and submitted to the Environmental Commission for the approval.

Figure 7. 3D photorealistic view (courtesy of Venice Link)

Figure 8. 3D photorealistic view (courtesy of Venice Link)

From the above pictures it is possible to see that the use of this kind of split concrete block as a facing gave to the embankment a much environmentally friendly look, similar to a natural rock wall rather than a to a reinforced concrete retaining wall.

DETAILS ON THE EXECUTION OF THE WORKS

The building of a geogrid reinforced segmental retaining wall is quite simple and fast, therefore the whole construction work had been executed very quickly, especially if compared with the traditional solution of a concrete retaining wall founded on deep piles.

The noteworthy issues concerning the realization of the geogrid reinforced segmental retaining wall at Preganziol overpass are the following:

- casting of an unreinforced poor concrete levelling pad, 15 cm thick and 100 cm wide directly on the compacted foundation soil, with a perfectly horizontal surface to insure full contact to the base surface of the first course of blocks
- perfect coordination on site between the subcontractor who was in charge of building the segmental retaining walls (blocks, geogrids and reinforced fill) and the main contractor who was in charge of laying and compaction of the unreinforced embankment core
- quick execution of the works: every working day 70 square meters of facing had been executed by a team of seven workers, using a roller and an excavator
- safety of the workers: it was guaranteed by fastening every worker to a steel cable which run parallel to the facing, anchored to big concrete blocks (see Figure 9)

Figure 9. Safety measures for workers

Figure 10. View of the segmental retaining wall

Figure 11. View of the segmental retaining wall

Figure 12. View of the segmental retaining wall

CONCLUSION

The choice of reinforced segmental retaining walls with PVA geogrids proved to be a valid alternative to standard concrete retaining walls, both from the technical and aesthetic points of view.

Due to the flexibility of the system it has been possible to achieve a much better behaviour than rigid concrete walls founded on piles in terms of elasticity and in terms of possibility of redistributing absolute and differential settlements.

Thanks to their good chemical resistance in alkaline environments, it is possible to use PVA geogrids as reinforcing elements also in embankments where lime stabilized soil is used as fill material (pH > 12), thus opening a new alternative where the use of other types of reinforcements is not possible.

The geogrid reinforced segmental retaining walls technique gave the possibility of building the whole embankment together with the wall, while in case of concrete structures the contractor would have to wait for the curing of the concrete before laying and compaction of the embankment fill.

Furthermore all the aesthetic prescriptions have been fulfilled, giving to the embankment an environmentally friendly look; the concrete blocks were also used as a facing for the bridge abutments, thus giving a harmonized look to the whole structure.

The first of the two embankments approaching the bridge have been completed last winter (4.000 square meters of facing), while the other one in currently in the construction stage winter (4.000 square meters of facing).

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