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Road ramps reinforced with geosynthetics in substitution of a traditional design solution

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ABSTRACT: The use of geogrids and geotextiles to support and reinforce embankments with steep slopes on both sides, built on soft soils, can be a valuable alternative to traditional retaining walls. In this paper a case is presented where the substitution of the original designed concrete retaining walls, founded on piles, with embankments reinforced with geosynthetics ended up in a significant cost and time saving, assuring an equivalent final product, with low environmental impact, although the existing foundation soils are mainly soft to firm cohesive materials.

1 INTRODUCTION

The original design of the state road S.S. n° 500 of Lonigo, located in north Italy, included reinforced concrete retaining walls for the approaching ramps to a bridge, due to problems of land availability. The walls, standing at both sides of the ramps, should have been founded on piles rested on deep sandy layers, due to the poor geotechnical characteristics of the superficial soil. This expensive solution would have required a long construction time not compatible with scheduled completion of the road.

As a variation to the original design, an alternative solution has been proposed by replacing the concrete walls with an embankment reinforced along the side with PET woven geogrids to support the steep slopes and, at the base, with two layers of a high strength woven geotextile crossing completely the cross section.

The maximum height of the embankment, including the foundation, was 9.50 m approx. The section in the upper part was trapezoidal with front faces inclined 80° and height up to 7.5 m. At the bottom, a wider bearing platform 2 m thick has been added founded at – 0.95 m below the ground level. Since the groundwater level was found at a depth varying between – 1.0 m to –1.5 m, it has been possible to work in dry conditions without removing the saturated subgrade and thus allowing an easy compaction of the filling.

Figure 1. 400 kN/m woven geotextile partially covered with filling material.

The structural configuration of the steep reinforced slopes has been optimized by changing the strength and the anchor length of geogrids with the wall height. Due to the high slope of the faces, the space between layers has been fixed in 0.50 m in order to prevent undesirable deformations and, in addition, a permanent erosion control net has been placed between the geogrids and the soil. Lost shuttering made with steel net have been used to build and to keep the faces straight.

Till 3.5 m from the top of the embankment, due to the lower level of stresses, geogrids with an ultimate tensile strength of 35 kN/m have been used; in the lower part of the embankment stiffer geogrids have been chosen with an ultimate tensile strength of 55 kN/m, as shown in Figure 3.

At the base of the embankment the two layers of 400 kN/m PET/PA woven geotextile have been used to guarantee the overall stability and to reduce relative settlements.

Basaltic granular mix has been used as filling material for the body of the embankment, whereas, close to the faces, a layer of humus has been added to favour the development of vegetation.

Figure 2. Steep reinforced slope during construction phase.

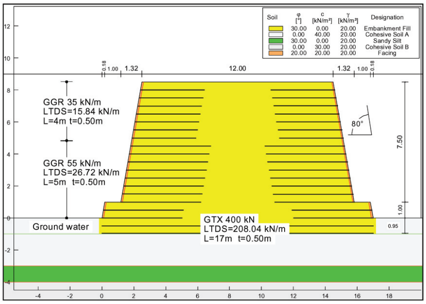

Figure 3. Typical cross section.

2 GROUND CONDITIONS

The total length of the road is around 5 km and the total length of reinforced embankment with geogrids and geotextiles is some 200 m. Ground conditions vary along the road; the worst, described below, are the ones corresponding to the embankment to cross the S.P. 134 at km 2 + 350:

- below ground level and until 2 ÷ 3 m below ground level there are mainly firm cohesive soils (Pocket Penetrometer (Pen) = 100 ÷ 300 kPa; Torvane (Tor) = 60 ÷> 100 kPa; Static penetrometer cone resistance q_c = 1 ÷ 2 MPa);
- following there is a 1.5 ÷ 2m thick layer of dense sandy silt (q_c = 6 ÷ 7 MPa);
- until 15 m below ground level there are mainly soft to firm cohesive soils (Pen = 50 ÷ 100 kPa; Tor = 20 ÷ 50 kPa; q_c = 0.5 ÷ 1 MPa), interstratified with lenses of dense silty sand and sandy silt (q_c = 12 ÷ 20 MPa); the laboratory tests have determined medium plasticity characteristics for the cohesive soil (plastic index I_p = 20 ÷ 25; liquid limit W_l = 38 ÷ 44);
- between –15 and –20 m there are alternating layers of soft to firm silty and clayey soil (Pen = 50 ÷ 150 kPa; Tor = 20 ÷ 60 kPa) and dense sand and silty sand (q_c = 6 ÷ 12 MPa; N_{SPT} = 27 ÷ 36 number of blows with Standard Penetration Test);
- until –25 m there is a layer of clayey silt and silty clay with some local and isolated lenses of peat; the cohesive soils are soft to firm in the upper part of the layer (Pen = 50 ÷ 150 kPa; Tor = 25 ÷ 50 kPa) and firm in the lower part (Pen = 150 ÷ 300 kPa; Tor = 60 ÷> 100 kPa); the laboratory tests have determined medium-low plasticity characteristics for the cohesive soil (I_p = 12; W_l = 37);
- from –25 m to the maximum depth explored (30 m) there is a layer of dense gravely sand (q_c = 15 ÷ 20 MPa; N_{SPT} = 30 ÷ 38).

Groundwater level was found at a depth varying between – 1.0 m to –1.5 m from the ground level, has shown in Figure 4.

Figure 4. Groundwater level at the base of the embankment.

During design a maximum settlement of foundations soils has been estimated of approximately 35 cm developing over a period of 8 ÷ 10 months.

The measures carried out during construction and after completion confirmed the prevision.

3 GEOSYNTHETICS CHARACTERISTICS

In order to optimize the costs, the steep slopes at both sides of the ramp has been reinforced by the use of two types of PET geogrids, while a double layer of a high strength PET geotextile has been layed at the base of the embankment. The materials have the characteristics shown in Table 1.

LTDS (long term design strength) for every material has been calculated according to the BS 8006 and the reduction factors have been supported by certified laboratory tests.

$$\text{LTDS} = \frac{F_{\text{creep}} \cdot P_{\text{ult}}}{f_m \cdot f_d \cdot f_e}$$

The reliability of these values has a fundamental importance in the design as they directly affect the overall safety factor of the project.

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 % of the ultimate tensile strength (UTS). In Figure 5

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Table 1. Geogrid and geotextile characteristics.

Material	Stabilenka 400	Fortrac 35	Fortrac 55
Description	PET/PA Woven fabric	PET Woven geogrid with polymeric coating	
Tensile strength (longitudinal)	400 kN/m	35 kN/m	55 kN/m
Elongation	≤ 10.0%	≤ 12.5%	≤ 12.5%
F_{creep}: creep reduction factor (120 yrs)	0.66	0.60	0.60
f_m: reduction factor for extrapolation and manufacture (120 yrs)	1.10	1.10	1.10
f_d: reduction factor for mechanical damage (gravel and sand)	1.12	1.17	1.09
f_e: reduction factor for environmental effects ($4 \leq pH \leq 9$)	1.03	1.03	1.03
LTDS: Long Term Design Strength (120 yrs)	208.0 kN/m	15.8 kN/m	26.7 kN/m

the curves related to the 400 kN/m geotextile are shown. From this chart it possible to note how at 50% of the ultimate tensile stress the difference between the immediate (5%) and the long term strain (6%) is very low.

The face of the wall has been protected against erosion with a permanent synthetic mesh (3.5 × 3.5 mm). This kind of protection has been preferred instead of biodegradable mats because the high inclination of the slope could not guarantee a perfect grow of the vegetation in some areas.

As a lost shuttering a steel mesh (Φ 8 mm, 15 cm × 15 cm) has been used, in order to achieve an uniform face with a regular slope of 80°.

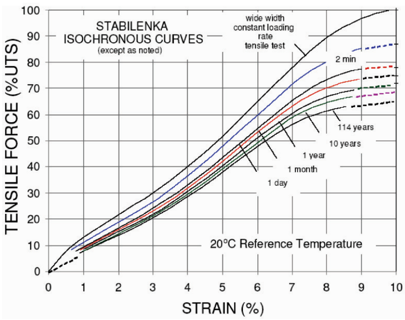

Figure 5. Isochronous stress-strain curves for the Stabilenka Product Line.

Figure 6. Embankment completed.

4 GLOBAL AND INTERNAL STABILITY

Global stability of embankment has been verified with the simplified method of Bishop (1955), assuming circular potential failure surface of radius r. The safety factor F is 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 limiting equilibrium: $F = \tau_f/\tau_m$.

The LTDS of the geotextiles and geogrids is taken into account in the determination of the safety factor F, that is always greater than 1.3 as requested by the Italian standards.

The analysis has been carried out with the software Slope commercialized by Rocscience.

In Figure 7 the geometry of a typical cross section used for the analysis is shown, where the different types of geogrids used have different colours, and the geotechnical characteristics of the ground assumed for the analysis are highlighted.

The internal stability of the steep reinforced slopes, has been performed analyzing circular (Bishop) and polygonal (Janbu) failure surfaces that completely cross the reinforced body, whereas for the compound stability analysis the failure surfaces that partially cross the reinforced soil have been considered.

When a reinforcement is crossed by a failure surface, it acts increasing the shear strength of the soil and, being a stabilizing force, as a consequence

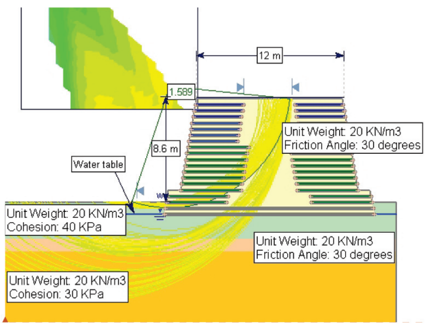

Figure 7. Stability analysis.

also the safety factor is increased. In this way, trough an interactive procedure, the LTDS of the reinforcement can be changed in order to reach the requested factor of safety.

At the same time, the length of the reinforcement at the back of any potential failure surface (stable zone) should be enough in order to avoid pull out effects. With this regards, has been considered a reduced friction angle (φ) between soil and reinforcement ($\tan \varphi = 0.80 \cdot \tan \varphi_{soil}$).

5 CONCLUSIONS

The choice of embankments reinforced along the side with geogrids to support the steep slopes, as alternative solution to the original design of concrete walls and piles, resulted in a significant cost saving of approximately 35 ÷ 40% of the project budget and also in a time saving.

Moreover, three years after completion, the road surface is still perfectly straight and no sign of relative settlements are evident, demonstrating the reliability of embankments reinforced with geosynthetics on soft cohesive soils.

Although a good vegetation cover on the wall faces has been reached in this case, in general it is suggested to keep the slopes up to 70° if no detailed information about the bio-climatic situation is available during the design phase.

In conclusion, it has been possible to avoid the execution of the piles under the retaining concrete walls and this alternative solution significantly reduced the final cost, the duration of the works and allowed to carry out the construction with low environmental impact.

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