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Highway Frejus Torino: A case history of a green reclamation around a highway viaduct with geogrid reinforced walls

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ABSTRACT: The paper describes the study, design and execution of vegetated geogrid reinforced slopes used to recover a degraded area due to the construction of Deveys viaduct (1992) on the new highway connecting Italy and France through Frejus tunnel. Reinforced slopes of height varying from 3 meters to about 20 meters using different bioengineering techniques has been adopted to obtain a well established and permanent vegetation cover.

INTRODUCTION

This project regards the green reclamation of a portion of the middle versant of the orographic left-side of the VAL DI SUSA, delimited westwards by the entrance of the tunnel SERRE LA VOUTE, eastwards by the entrance of the tunnel CELS and placed south of the inhabited area of Deveys, where the Deveys viaduct, which is part of the new section of the TORINO-BARDONECCHIA motorway, has been built. The recovery of the area has become necessary mainly after the collocation of the viaduct piers along the slope, which was so steep to require the creation of a series of access ramps which determined a profound change of the original slope. The works for the environmental rearrangement and recovery of the area were therefore aimed at restoring the area compatibility with the surrounding landscape and to recover the structural homogeneousness of the land. Among the various minimization works, the most important both for quantity and quality have certainly been the reinforced vegetated steep-slopes with height between 3 and 20 m with a slope angle of 70°. This paper gives an example of proper utilization of geosynthetics together with bioengineering technics allowing results which could not be obtained otherwise both as regards costs and environmental impact.

GEOLOGICAL FEATURES

The Susa Valley has formed from Salbertrand to Gravere mainly along the tectonic contract of two formations:

- "the Lime-schist with green stones" (Piedmontese Mesozoic) constituting the right-side orographic slope;
- "the Metamorphites" (quarzite mica-schists) belonging to the "Series d'Ambin" and to the "Series of Clarea" (the first of which Permian, the second presumably Carboniferous) emerging to form the relieves of the left-side orographic slope.

In particular, this area is formed by thick and wide layers of gneiss and mica-schist. The same layers are surmounted by Triassic formations: quartzstone and limestone.

While the last two items emerge only on the top of the slopes, the gneiss and the mica-schist formations emerge in various zones along the side: in the upper zone the layers are slight, in the middle area, where is located the work, are inclined in south-east direction according to the slope.

The slope remained stable either before the construction works and after the collocation of the piers.

DESCRIPTION OF THE WORKS

As mentioned before the piers of the Deveys viaduct had necessarily to be collocated on the middle left-hand slope of the Susa valley in proximity of the inhabitated area of Deveys. The slope under examination has an inclination of 45° and is hardly accessible from the National road n. 24, constructed on the higher part of the slope. In particular the pier foundations are placed between 10 and 30 m under the National road n. 24. Thus the creation of access ramps became necessary both for the access of trucks and machinery during the building phase and later to keep a check on the piers. The consequent remodeling of the slope due to the presence of very high piers and to the presence of retaining concrete walls at the foundations of the piers, brought to extensive environmental damage of the area which required an intervention aimed at minimizing the concrete works. Related to this there were 3 main problems to solve:

- the camouflaging of the concrete retainment walls
- the protection and camouflaging of the rock slopes resulting from the excavation
- the partial camouflaging of the pier foundations

To achieve these goals in spite of the lack of available space, a problem made even worse by the fact that it was necessary to leave an access to the piers once the construction works were finished, soil with a slope angle greater than that of any loose material was needed to create reinforced steep-slope which could be easily vegetated. The height of the projected steep-slope varies between 3 to about 20 m with an inclination of about 70°. Of particular interest, among the various works extending for about 300 m, are the 20 m high steep-slopes works consisting of 4 berms respectively high 8, 4.2, 4 and 3.2 m The function of the first berm - 8 m high - besides being the support for the upper berms is to provide on its top a 3.5 wide access ramp to the piers; the function of the other three berms of a total height of 12 m is to camouflage the concrete wall protecting the foundations of the piers. The advantages offered by this technology, besides the already mentioned excellent environmental and landscape compatibility once the vegetation has covered the slopes, have been the low costs of the works allowed by the cost of the material, by the quick realization and by the possibility of making the structures operative immediately and without any reduction of safety, as well as by the easy realization due both to the fact that no particular equipment is needed and that it is possible to reuse the materials directly from the adjacent excavations.

FILL AND REINFORCEMENT GRIDS PROPERTIES

As fill material of the steep-slopes the locally available soil deriving mainly from the nearby excavations has been used, having the following geotechnical properties:

Table 1

Internal friction angle ϕ	30°
Cohesion C	0
Unit weight γ	19 kN/m³

It has been supposed the total absence of interstitial pressures and therefore a perfect drainage of the walls.

Table 2: characteristics of Fortrac geogrid.

FORTRAC		55	80	110
Mass per unit area	g/m²	360	550	560
Short term tensile strength - warp direction	kN/m	55	80	110
Short term tensile strength - weft direction	kN/m	30	30	30
Elongation at break - warp direction	%	12,5	12,5	12,5
Elongation at break - weft direction	%	12,5	12,5	12,5
Creep of the yarns under load of 60% after 2 years	%	<2	<2	<2

Three types of geogrids Fortrac manufactured by AKZO NOBEL GEOSYNTHETICS bv and marketed in Italy by SEIC spa have been used: Fortrac 110/30-20 for the two lower berms, Fortrac 80/30-20 for the middle berm and Fortrac 55/30-20 for the upper berm having mechanical properties summarized in Table 2.

Fortrac geogrids have been manufactured with Diolen 164S yarn made from polyester fibers and woven into a 22.86 x 22.86 grid and coated with a protective layer of black polyvinyl chloride (PVC) ensuring a good protection both against mechanical damage and damage from ultraviolet light.

DESIGN DATA OF THE GEOGRID REINFORCED WALL

To design the reinforced steep-slopes an algorithm based on the Jewell method (1991) has been adopted. The tensile strength has been determined considering a design life of the structure of 120 years and a characteristic strength of 60% of short terms tensile strength (fig. 1).

$$P_{car} = P_{ult} \cdot 0.6$$

The characteristic strength has been reduced using a safety factor f_m.

$$P_{amm.} = P_{cart} / f_m$$

This safety factor incorporates various partial safety factors:

$$f_m = f_{m1} \cdot f_{m2}$$

f_{m1} allows for variations in the yarn due to its

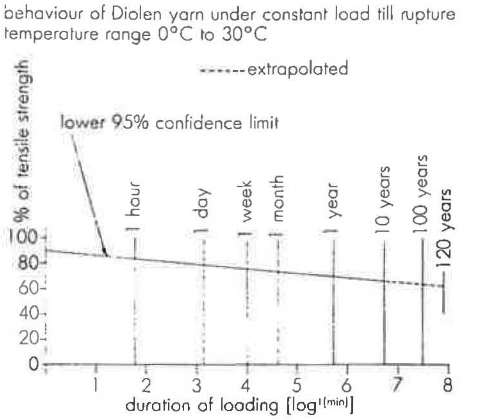

Figure 1: Time to rupture for a given design load

Table 3

Design life (years)	**Safety factors (f_{m1})**
120	1.3
60	1.2

Table 4

Material fill	**Maximum particle size (mm)**	**Safety factor f_{m21}**
coarse aggregate	60 - 125	1.40
gravel	2 - 60	1.30
sand	≤ 2	1.10

Table 5

Soil pH level	**Safety factor f_{m21}**
9.0 - 9.5	1.15
4.1 - 8.9	1.00
2.0 - 4.0	1.10

manufacturing and to possible mistakes in the extrapolation of data to determine the long term characteristic tensile strength (table 3).
The safety factor $f_{m2} = f_{m21} \cdot f_{m22}$ allows for possible installation damage due to mechanical damage during installation (f_{m21}) (table 4) and to environmental effects deriving from the soil pH level (f_{m22}) (table 5).
The parameters for the soil/grid interaction are those adopted by the Jewell method:
the direct sliding coefficient and bond coefficient.
The direct sliding coefficient f_{ds} is a measure of the reduced sliding coefficient f_{ds} tg (ϕ) for preferential sliding along the surface of a reinforced layer. The sliding resistance is made from :

- skin friction tg(δ) which acts over the portion of the plane sliding area (αs)
- the full shearing resistance of the soil tg(ϕ) which acts over the area of soil to soil contact ($1 - \alpha_s$)

$$f_{ds} = \alpha_s \, f_{sf} + (1-\alpha_s)$$

where:
f_{sf} is the coefficient of skin friction determined by tg(δ)/tg(ϕ);
α_s is proportion of the plane sliding area that is solid.
Considering for the Fortrac geogrid an $\alpha s = 0.30$ and f_{sf}=0.6 deriving from the tested data we have obtained an f_{ds} = 0.84.
The bond coefficient f_b allows the possibility that the geosynthetic could be pulled out and depends on:

- friction tgδ acting on the parts of the geosynthetic actually in contact with the soil
- the soil bearing capacity in the warp direction of the grid

As a whole, the bond coefficient is obtained:

$$f_b = \alpha_s \left(\frac{tg\delta}{tg\phi} \right) + \left(\frac{\alpha_b \cdot B}{S} \right) \left(\frac{\sigma_b}{\sigma_n} \right) \frac{1}{2tg\phi}$$

Fig. 2. Detail of the wall during the contruction, showing the geogrids, biofelt and the formwork.

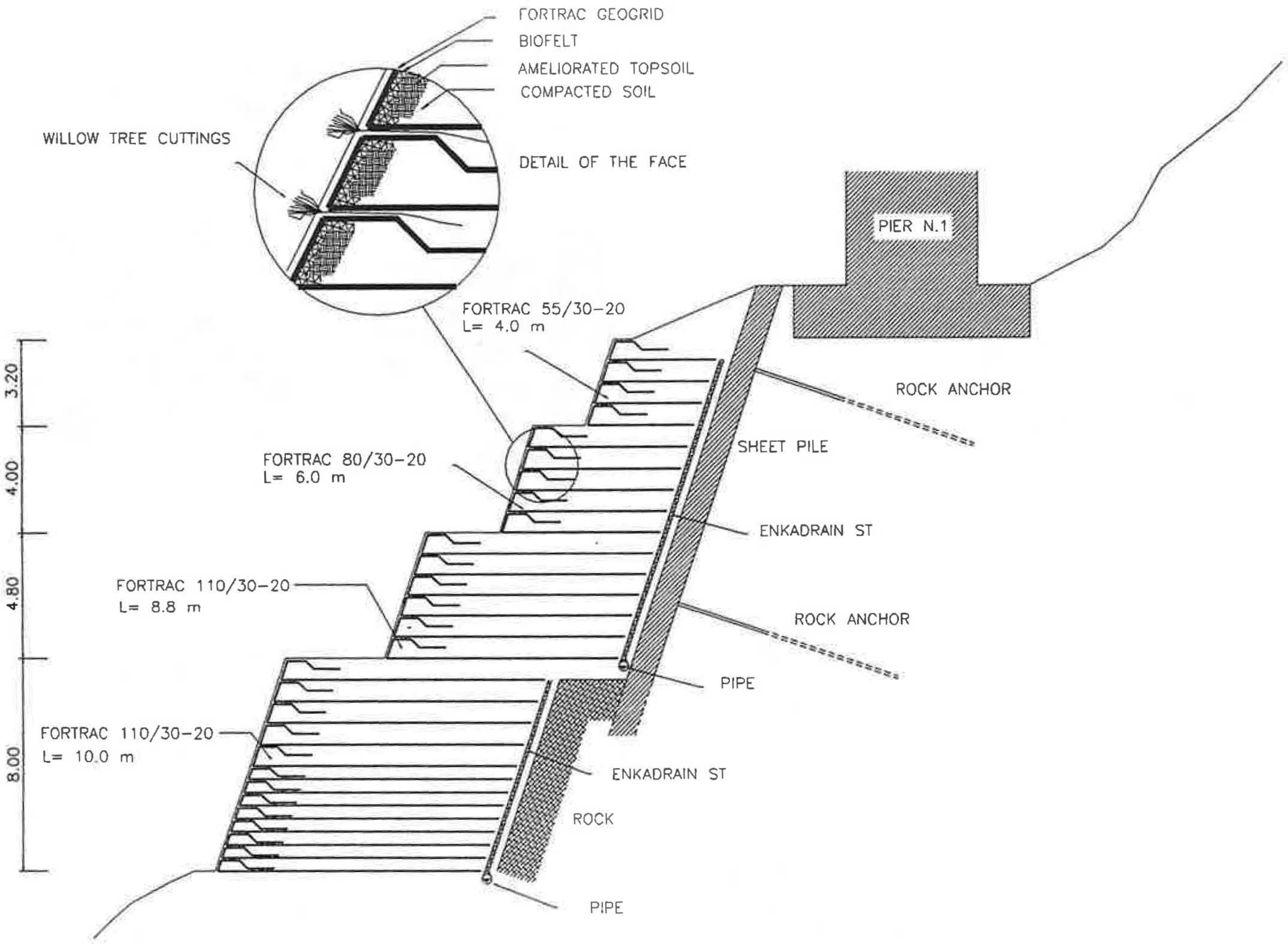

Figure n. 3: Cross section of the geogrid reinforced wall

Fig n. 4: View of the slope before the construction of the reinforced walls

Fig. n. 5 : Detail of drainage with geocomposite behind the walls

Fig. n. 6: Detail of the face with the willow tree cuttings between layers

Fig. n. 7: View of the reinforced walls at the end of construction

where
α_b is proportion of total reinforcement bearing surface available surface;
B is thickness of the geogrid;
S mesh opening size;

$$\frac{\sigma_b}{\sigma_t} = \mathrm{tg}\left[\frac{\pi}{4} + \frac{\phi}{2}\right] \exp\left(\left[\frac{\pi}{2} + \phi\right] \mathrm{tg}\phi\right)$$

is the bearing capacity ratio.

f_b can be assumed for the Fortrac geogrid ≥ 0.5. With these parameters the vertical spacing vary from 0.50 to 0.80 m and the lengths of the reinforcement vary for the different berms from 10 to 4 m (see the figure 4).
With this typology of reinforcements it has been subsequently possible to check the internal stability of the works obtaining a value of the safety factor greater than 1.3.

CONSTRUCTION METHODS

The classical construction method for these types of works has been adopted for the construction of the steep slopes, paying particular attention to the vegetation cover of the facing slope. In the first place it has been necessary to compact the top layer, subsequently creating a series of layers by means of a mobile formwork consisting of planks and metal tubes removed at the completion of each layer. The fill material has been compacted in successive layers of maximum 300 mm by means of a small roller so as to obtain a density of at least 90% of the maximal density obtained with the modified Proctor test. In spite of its poor quality, the soil from the excavation site has been used and its integration with the reinforcement elements has been perfect, thus saving a considerable amount of time and minimizing the costs related to the supplying and transport of fill material. Along the facing a biofelt has been placed on the internal part of the wraps so as to prevent the erosion of soil before the vegetation growth. A layer of 100-200 mm top soil has been placed to settle the facing wall and to ensure that the vegetation takes root. The top soil has been carefully selected, it was ameliorated including water retention granules, slow release fertilizer (Nitrogen, phosphate, potassium base) and peat compost. The facing has been subsequently hydroseeded with a mixture of autoctonus vegetation drought resistant; willow-tree cuttings have also been inserted between each layer to ensure a stable vegetation cover even in drought periods being the wood-roots deeper than those of the other vegetation. Due to the presence of water in the slope and the scarce permeability of the soil, a drainage system has been provided behind the works to prevent interstitial pressure. The drainage consists of the drainage geocomposite Enkadrain ST with a collector tube at the base. The Enkadrain is a three-dimensional composite which consists of a drainage layer sandwiched between two geotextile filters. The drainage layer is composed of tough, looped nylon filaments which are fused together where they cross, forming an open-structured material with a voids ratio of 95 %. The geotextile filter layers are made of heatbonded polyester core/nylon sheath non-woven fabric, with a thickness of 0.7 mm.
Due mainly to the flexibility and manageability of the geogrids allowing a perfect fitting to the slope it has been possible to lay 20.000 sqm of geogrid in a very short time and use the structure immediately without any waste of time; the natural aspect of the slope which is a consequence of the vegetation cover has restored the slope's compatibility with the surrounding environment.

CONCLUSIONS

In conclusion, it is possible to maintain that the use of the reinforced steep-slopes method with geogrids, has allowed to minimize the environmental impact of the slope thanks mainly to the vegetation cover of the facing walls obtained with simple methods and low costs ensuring at the same time a perfect static functionality of the works. Thus it is possible to infer that a good use of the geosynthetics can solve extremely difficult problems with due respect for the environment.

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