Reinforced trapezoidal embankment for the protection of a road against an active landslide from the side of a quarry

Russo, L. E.
Huesker srl – Trieste - Italy

Balducci, M.
Area Progetto e Associati – Perugia - Italy

Fantini, P.
Huesker srl – Trieste - Italy

Keywords: embankment, soil reinforcement, geogrid, landslide, rock fall protection, high strength

ABSTRACT: This paper relates the construction of a huge trapezoidal embankment at the side of an old inactive quarry, in which a massive landslide body has been activated, in order to create a safety barrier as a provisional protection of the provincial road SP 249 that runs along the toe. Due to the risky situation, the road was closed cutting off the main of the two possible ways to reach two mountain villages. For these reasons it has been necessary to find out a technical solution that could be executed in a very short period of time and, at the same time, had to be safe, environmental friendly and cost effective. Therefore, to fulfil geometrical, temporal and aesthetics requirements, has been adopted a double face steep slope reinforced with geogrids.
The impact energy and the landslide volume have been considered to define the embankment geometry. Overall stability problems have been solved by means of long high strength geogrids (1,000 kN/m) placed at the base of the embankment. A drainage blanket of stones filtered with high permeability woven geotextile has been adopted to evacuate the water coming from the back.

1 INTRODUCTION

The provincial road SP 249 runs along the toe of an old inactive quarry, located in Torgiovannetto near the city of Assisi (Italy). In December 2005 the authorities have been forced to close completely the road due to the activation of a massive sliding body in the quarry side (figure 1), interrupting the main of the two possible ways to reach the towns Costa di Trex and Armezzano.

Figure 1. Panoramic view of the quarry from the top

Geological investigations and an extensive monitoring campaign have revealed a huge mass of soil sliding slowly down as unique body of 180,000 m^3. This risky situation was still further aggravated due to the seismicity of that region (figure 2).

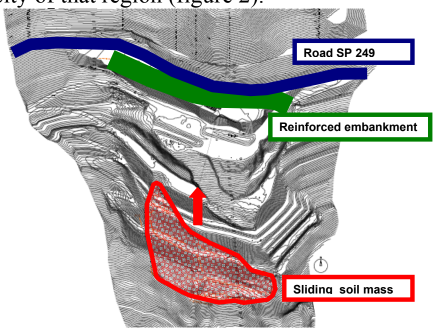

Figure 2. plan of the quarry, sliding body, reinforced embankment and road at the toe.

The quickest way to get the reopening of the road was to create a barrier at the toe, able to resist the impact of the expected landslide and functioning, at the same time, as dam for the basin created at the mountain side that should have enough capacity to hold the predicted volume of soil.

The design solution has been addressed to the construction of a trapezoidal embankment reinforced with geogrids.

2 SOIL PARAMETERS

After the evaluation of all data collected by means of field and laboratory tests, the structural and lithostratigraphic characteristics of the whole area involved in the work have been defined.
In general line, the soil layers are constituted by a superficial layer of heterogeneous filling material, laid on a calcareous debris layer, which rests on a bed rock. Thicknesses of soil layer and its variation have been defined along the ground profile. The geotechnical characteristics of the filling soil for the embankment have been imposed.
The adopted soil parameters are shown in Table 1.

Table 1. Soil parameters

Soil description	Internal friction angle [°]	Cohesion [kN/m^2]	Unit weight [kN/m^3]
Filling soil	35	0	18.5
Superficial layer	28	0	19
Debris	32	10	19.5
Bed rock	30	175	24

3 ACTIONS: LANDSLIDE IMPACT AND SEISMIC STRESSES

Making use of a dynamic model applied to the sliding mass, the height and the velocity of the debris flowing have been estimated. The impact stress on the back face of the embankment has been calculated according with the following formula:

$$F = K \cdot \gamma / g \cdot h \cdot v^2 \cdot \sin\beta$$

with:
K = 2 $\rightarrow$ dynamic impact coefficient
γ = 20 kN/m^3 $\rightarrow$ soil unit weight
g = 9.81 m/s^2 $\rightarrow$ gravity acceleration
h = variable (m) $\rightarrow$ debris flow height
v = 6 m/s $\rightarrow$ debris flow velocity
β = 80° $\rightarrow$ flow direction/back face angle

The resultant force has been distributed uniformly at every section for a total height of 1.5 times the debris height. Taking into consideration every height, pressures and the required basin capacity, the embankment geometry has been defined.
Regarding the seismic effect, even if the embankment was designed as provisional work (design life 5 years), due to the high risk of landslide activation in case of earthquake, for design purposes and after a probabilistic analysis, it has been adopted a seismic horizontal acceleration of a/g = 0.07 (foreseen for works with design life of 50 years, according with the Italian standards), instead of the more plausible a/g = 0.03 for earthquake acceleration with 10% of provability to be exceeded in 5 years in that particular location, in order to remain on the conservative side.

4 ADOPTED SOLUTION

The nature of the energy developed in case of a landslide of 180,000 m^3 of soil mass running at 6 m/s, steered the design solution to create a voluminous dam able to resist the impact. On the other hand, the scarcity of available room and the need to achieve a capable basin at its back avoiding, at he same time, the risk of overtopping; leaded to opt for a high trapezoidal embankment reinforced with geogrids in order to get very steep slopes and a shock-resistant soil mass.
The steep reinforced embankment fulfils another essential condition: the construction time. The extreme necessity of reopening the road required a solution that could be constructed in a very short period of time. This is a positive characteristic of this type of works that can be done very quickly without downtimes. The weather condition doesn't influence significantly the production if a good organization and QC is implemented.
This solution was fastest and cost effective compared with, for instance, concrete walls founded on piles and, furthermore, from the landscape point of view, allowed to obtain a natural appearance minimizing the environmental impact. All these aspects have been essentials to get the approval of several pertinent authorities.

4.1 Embankment geometry
The variable height of the embankment over the road level has been represented by four typical sections varying from 6 to 15 m approximately and the width at the base varies from 12 to 13 m. The crest width was set at 4 m. The slope at the basin side has been fixed as 80° in order to gain basin volume and to perform better against the flow impact, while at the road side the inclination has been fixed as 65° to facilitate the vegetation growing and to get a lower environmental impact.

4.2 Reinforcement with geogrids
The embankment has been reinforced using different types of flexible high modulus PET geogrids with strengths varying from 110 kN/m at the bottom, to 35 kN/m at the top, in order to optimize the costs (figure 3 and table 2).
Because the embankment was founded on soil layers with scanty geotechnical characteristics and the rock

bed laid deep, it was necessary to adopt long double layers of high strength PET geogrids (1,000 kN/m strength and up to 32.5 m long each) at the foundation level, in order to guarantee the overall stability of the whole versant, with particular regard in case of soil accumulation at the basin side. The base reinforcement with geogrids allowed to bring down the costs up to 50% compare with traditional solutions like piles or nailing. Furthermore, from a structural point of view, this choice was compatible with the rest of the structure in terms of flexibility, and allowed to execute the works in a short period of time.

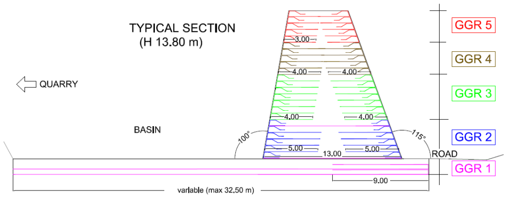

Figure 3. Structural configuration of the embankment

Technical characteristics of adopted geogrids are shown in table 2. The Long Term Design Strength (LTDS) adopted for stability calculations has been obtained applying specific reduction factors taken from certificates issued by accredited independent institutes for any single model of geogrid. This respect is an important issue, which should not be underestimated, because the safety level of the work is directly dependent on the reliability of these values.

Table 2. Technical characteristics of adopted geogrids

Geogrid type	**GGR 1**	**GGR 2**	**GGR3**	**GGR 4**	**GGR 5**
	Fortrac 1000 T	**Fortrac 110 T**	**Fortrac 80 T**	**Fortrac 55 T**	**Fortrac 35 T**
Tensile strength [kN/m]	≥ 1000	≥ 110	≥ 80	≥ 55	≥ 35
Max strain [%]	≤ 10.0	≤ 8.5	≤ 8.5	≤ 8.5	≤ 8.5
Max. strain at design strength [%]	≤ 6.0	≤ 5.5	≤ 5.5	≤ 5.5	≤ 5.5
Creep (10 yrs at 50% tensile strength) [%]	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
LTDS [kN/m]	567.0	65.59	47.70	30.78	18.67

4.3 Drainage layer and erosion control

The first layer of the embankment has been made with coarse gravel in order to obtain a drainage mattress at the base, able to discharge the water coming from the basin side and, with particular regard, in case of landslide. The drainage layer has been protected against clogging with a suitable woven filter geotextile (figure 4). A woven filter has been preferred instead of a non woven geotextile because its high permeability and less tendency to clogging, as well as because of the high resistance against mechanical damage during installation.

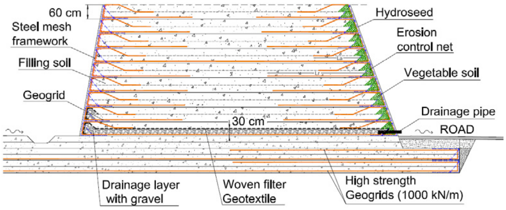

Figure 4. Section detail. Drainage layer with a woven filter

Inside the front of every layer, a coated polyester net (mesh size 3.5 mm) has been placed as erosion control mesh.

5 DESIGN CALCULATION

Stability calculations under different combinations of actions have been performed and, in particular have been analysed:

(a) The shear resistance against sliding at the base of the embankment and at every level of reinforcing geogrids. With this regard a reduced angle of friction along the interface geogrid /soil has been adopted (reduction factor 0.8)

(b) Safety against overturning (min FS > 1.5)

(c) Bearing capacity of foundation soil at the base of the embankment

(d) Settlements along the cross sections of the embankment. Maximum estimated settlements: at the centre δ_{max}=10.3 cm, at the sides δ_{max}=4.0 cm.

(e) Internal, compound and overall stability of the embankment, using circular (Bishop) and polygonal (Janbu) sliding surfaces. Analysis of different scenarios: before and after the landslide, with and without seismic action, with and without water pressures. (figures 5 and 6).

(f) Impact of an individual rocky body with diameter 1.5 m, weight 4,600 kg, travelling at 15 m/s with a kinetic energy of 52.7 kJ.

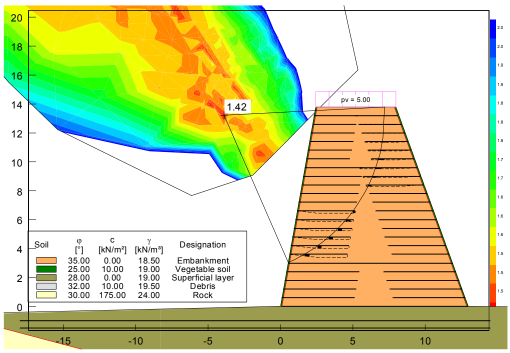

Figure 5. Example of internal stability calculation (back side)

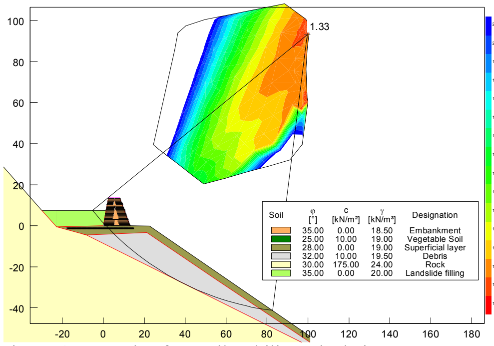

Figure 6. Example of overall stability calculation

6 CONSTRUCTION

The construction have been made following the usual practice for the execution of steep reinforced slopes but using different steel mesh frameworks for each face, that is inclined 65° at the road side and 80° at the back. Compaction and density of the filling have been controlled trough bearing plate and proctor tests.


Figure 7. Trapezoidal embankment during construction (basin side inclined 80°)


Figure 8. Final situation at the road side (front slope 65°)

A vegetable soil layer has been placed only along the front of the road side in order to facilitate the vegetation growing. The total length of the embankment was 170 m approximately for a total facing surface of about 3,500 m^2 (vertical projection). The work has been executed in 4 months instead of the 6 months foreseen during design phase.

7 CONCLUSION

The trapezoidal embankment reinforced with geogrids revealed to be most suitable solution to face up the construction of the barrier protection against the active landslide, because fulfils technical and environmental requirements, that is to say:

(a) Short execution time, compared with other solutions like concrete walls founded on piles. That's allowed to minimize the risk in case of landside activation and to obtain the quickly reopening of the road for the almost isolated towns Costa di Trex and Armezzano.

(b) Suitable soil mass and robustness to withstand the sliding impact,

(c) Geometric versatility to be adapted in the topography of the area getting over geometrical restrictions as the proximity to the road, the need to reach a suitable basin capacity, the need to reach a minimum required height in order to avoid overtopping.

(d) Natural appearance to be introduced in the surrounding environment.

(e) Cost effective. Thanks to the adoption of high strength geogrids (1,000 kN/m) it was possible to avoid the use of piles and/or nails. This solution was on the whole more convenient compared to concrete walls founded on piles.

ACKNOWLEDGEMENTS

We would like to express our thanks to Mr. Simone Buttiglia (APA) and Andrea Valente (Huesker srl).

REFERENCES

British Standard BS 8006: (1995). Code of practice for strengthened/reinforced soils and other fills.

Decreto Ministeriale 11 May 1988. Public Works Minister

ERA report n. 2007-0072. Assessment of the long term durability of Fortrac T geogrids and derivation of reduction factors.

Hungr O., Morgan G.C., Kellerhals R. (1984). Quantitative analysis of drebris torrents hazards for design of remedial measures. *Canadian Geotechnical Journal ,21-Ottawa*