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A protective structure for mud flows in Northern Italy

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ABSTRACT: The paper describes a geogrid earth reinforced embankment constructed in Northern Italy. This particular and innovative protection barrier is derived by the experience made in the last years on reinforced soil barriers for rockfall protection. The nature of the area (consisting mainly in clay deposit) has required the use of the locally available soil, consisting of silty clays with high water content. To guarantee a proper interaction between the fill material and the reinforcement, a special type of geogrid has been used. Different aspects connected with the design are considered: static internal, external and global stability analyses of the structure were performed using traditional limit equilibrium analysis. An adequate drainage system, consisting in several longitudinal trenches passing under the embankment and filled with granular material has been provided at the base of the structure. Due to the nature of the soil it has been necessary to operate in the winter when the risk of rainfall was reduced. The whole structure, 65 m long and about 30 m wide at the base, has been constructed in 3 months.

1 INTRODUCTION

Debris and mud flows are usually regarded as a part of the more widely defined category of Fast Slope Movements. This kind of landslide includes rock falls, topplings, some slides and flows (from mud to debris). Due to their impact on human lives and to the difficulties related to their prediction, debris and mud flows are commonly considered to be among the most dangerous slope movements. A complete study of such phenomena should include three different stages: triggering (failure conditions), flow dynamic (propagation) and their interaction (impact) with containment structures such check dams, barriers, embankments.

Recent developments in the application of earth reinforced structures to rockfalls and rock avalanches, led to the execution of on site real-scale tests (Peila et al., 2000). Results showed a very good performance of earth reinforced structured behaviour against heavy boulder impacts, due to their mechanical flexibility and their capability of withstanding dynamic impact (damping). Furthermore, mainly in the last decade, earth reinforced structures proved to be a very good option for hydraulic applications (Cancelli et al., 2000), particularly for riverbanks and dike protection. These considerations suggest the possibility of considering the application of this technique to the realization of protective structures against debris and mud flows. The paper presents a solution for a protection structure from a mud flow in the Apennine mountains in Italy.

2 DEBRIS AND MUD FLOWS MITIGATION

Many different authors have already studied the problems related to debris flows mitigation and control highlighting that basically, structural and non-structural measures could be considered. Non structural measures for debris and mud flow hazard mitigation typically involve land planning and land management. Structural measures have high initial costs and usually require frequent maintenance: the most common method of controlling debris flows within channels or fans is typically by check dams or by debris basins.

In any case, every single structure should be carefully considered to suit local conditions. A careful choice of technical requirements can noticeably increase the effectiveness of debris flow protective structures in terms of cost effectiveness and technical effectiveness such as dynamic impacts strength, durability, drainage capability etc.

Also for this reason some authors recently started to consider the possibility of transferring to debris flows the experiences made on rock fall protection barriers. The application of flexible barriers to debris flows seems to be a very interesting solution for problems of small to average dimensions (impact energy up to 300 ÷ 400 kJ, and volumes up to 500 m^3). Larger volumes (many thousands of cubic meters) usually need to be controlled with debris basin, typically made with earth embankments: the solution described in the present paper is related to this type of problem.

Whenever it is necessary to face a dynamic impact, such as a debris basin embankment, the best solution is to provide a system having sufficient deformability and damping properties. A rigid barrier could be destroyed by the impact of the mass of water and rocks. Even a semi-rigid system (gabion walls) could have problems, as it would not be able to withstand great strains or stresses.

The type of effect that the impact of the debris flow can have on the barrier can be compared with the effect of a rock impacting on a geogrid reinforced rock fall protection barriers.

An important development in the study of reinforced soil structures are the studies made in the during the last couple of years on HDPE geogrid reinforced rockfall barriers (Peila et al., 2000).

These tests demonstrates the behaviour of a geogrid reinforced ground wall in case of impacts having energy much higher than the ones foreseeable for a debris flow in an arresting area such a debris basin.

3 THE VAL DI NIZZA MUD FLOW

The area of Val di Nizza is characterised by the presence of a layer of clays and silty clays, varying between 4.00 and 10.00 m thick, with high plasticity overlaying a bedrock consisting of clayey marl and marly clays.

Due to the very poor mechanical characteristics of the upper layer, in the late 40's the first movement of mud flows were observed. The movements were continuing, with a progressive increase of the area interested by the movements (with the top part going back towards the town of Poggio Ferrato between 1980 and 1990). In order to reduce the risk for the upper town, between 1986 and 1988 some consolidation works, consisting in the creation of draining trenches, were started.

The solution was not completely effective, and movements were not stopping. In 1996 a major movement was occurring; the mud flow was almost reaching the town of Casa Schiavo, about 1.50 km from the upper part of the landslide. The limits of the mud flow are indicated in Fig. 1.

A system of water collection and drainage by means of 4 3.00 m diameter connected concrete draining pits, were used.

The solution was effective in reducing the movements and to give temporary respite to the town

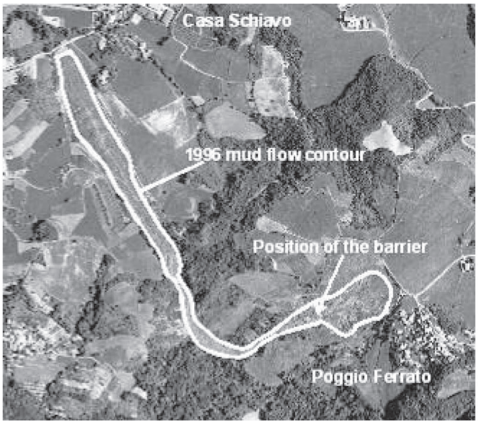

Figure 1. Mud flow contour and position of the barrier.

of Poggio Ferrato. However, the need to give a final solution to the problem was leading to a completely different solution, able to prevent future movements.

As anticipated before, the solution consisted of the creation of a barrier made with the locally available soil reinforced with geogrids. This barrier was created in an area were the mudflow was narrower due to the presence of two natural "shoulders" of emerging bedrock, with the bedrock itself only 5.00 m below the ground level in the central part (Fig. 2).

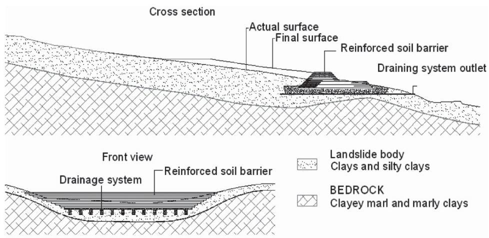

Figure 2. Cross section and front view.

3.1.1 *Proposed solution*

One of the main difficulties to be overcome in the design and the construction of the protection barrier was the nature of the soil. As described above, the area was characterised by the presence of soils with poor mechanical and frictional properties. The proposed barrier was a trapezoidal one, 6.00 m high on the upstream side. At the base a 1.00 m thick drainage layer will be placed; over this structure a steep slope would be constructed, inclined at 45° on the horizontal to allow for grass growth. The downstream side will be divided in two blocks; the lower one, 2.40 m high, will be separated from the upper one by a horizontal berm 10.0 m wide.

As shown in Fig. 2, the upstream side of the barrier was partially filled with the soil excavated during the operations of modelling of the area. A pipe was inserted

in the upper part of the barrier in order to allow the free passage of water. The upper portion of the dam has been left free to stop any future minor mudflow that could happen. The inlet of this pipe has to be monitored in order to maintain the water flow.
The amount of fill material that would be required to construct the barrier and the lack of good quality fill made it necessary to evaluate the possibility of using the existing soil as the fill material.

The steep side can be reinforced through the use of PP multi-layer extruded geogrid; this type of product has been chosen because of the good interaction with soil having a high content of fine particles. The geogrid required to provide internal stability were extruded PP multi-layer geogrids type TENAX MS 500, having the mechanical properties shown in Table 3. Multilayer geogrid, have a large number of strands able to distribute the stresses in a very uniform way, and to obtain a considerable "root-effect". The random distribution of apertures allows optimum interlocking with all grain dimensions, also very fine. The presence of five layers randomly positioned gives a high aperture distribution, and therefore a particularly high capability to interact with fine soils.

Table 1. mechanical and physical properties of the geogrid.

Properties	Value	Test method
Polymer type	PP	
Geogrid structure	Multi-layer Extruded PP	
Unit weight	315 g/m^2	ISO 9864
Peak tensile strength	35 kN/m	EN ISO 10319
Tensile strength at 2%	8 kN/m	EN ISO 10319

The geogrid reinforced slope was both designed in terms of internal and external stability, taking into account in the former case the behaviour of the structure when subjected to the static forces and in the latter case the behaviour of the structure when the debris flow has covered part of the upstream face of the structure.

From the internal stability analysis, performed using traditional design methods (Jewell, 1993), the geogrid length and the required spacing were calculated. Much more interesting, according to the authors, was the external stability analysis.

3.1.2 *External stability analyses*

The external force that can cause instability of the structure is the presence of a debris flow. The design assumptions for this verification have been shown before; in particular it has been assumed that the friction angle of the mud flow is equal at 10° (this value has been assessed observing the natural slope angle of this material in the arrested area after previously happened events).

The maximum height of the debris flow has been assumed to be 5.00 m above the ground level (thus allowing a clearance of 1.00 m). This means that the steep slope will be exposed to the debris flow for 5.00 m. A simplified scheme has been used to verify the external stability (Fig. 3).

The force transmitted by the mudflow has been

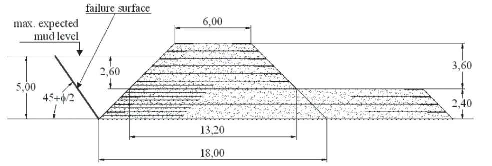

Figure 3. Simplified rigid body scheme for limit state external stability.

calculated using Coulomb's active thrust coefficient

$$K_a = \frac{\cos^2(\phi' - \alpha)}{\cos^2\alpha \cdot \cos(\delta + \alpha) \cdot \left[1 + \sqrt{\frac{\sin(\phi' + \delta) \cdot \sin(\phi' - i)}{\cos^2(\delta + \alpha) \cdot \cos^2(\alpha - i)}}\right]^2} \quad (1)$$

Where: ϕ' = mudflow friction angle (10°)
α = inclination of the face
i = inclination of the mudflow surface
δ = interface friction angle

The thrust has been assumed to be horizontal, and has been computed using Rankine equation.

The block weight will react with the base creating a friction resistance R. The resisting friction force is calculated multiplying the normal component by the interface friction angle, and applying a reduction factor (direct sliding coefficient) that takes into account the presence of the geosynthetic reinforcement. The factor of safety against sliding of the block is simply calculated as the ratio between the resisting and the sliding force. This analysis is valid in static case. A mud flow is a dynamic event, although the velocity foreseen at the impact with the barrier is quite low (1.00 m/sec). To take into account the dynamic effect the force has been amplified by a factor 1.20. In both static and dynamic condition the factors of safety calculated were satisfactory.

Two analyses have been performed: the first one at the base of the dam, where the width (and thus the reacting area) is greater; the second one at height corresponding to the lower base of the upper part of the dam. Both the analyses were giving FS adequate.

Another type of possible failure mechanism studied was a global stability failure. To verify that the presence of the earth barrier was not modifying the stability of the area, a global stability analysis using typical Bishop's modified approach has been followed. The results of one of the analyses performed is shown in Fig. 4.

One the most important aspects of the project was the creation of the drainage trenches at the base. Due to soil conditions that were worse than expected, the

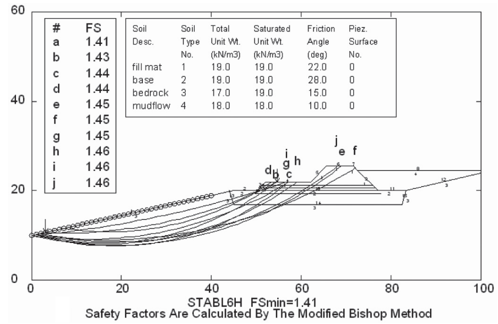

Figure 4. Global stability analysis.

trenches were deepened from the original 2.00 m to 4.00 m. At the end of the construction of the trenches it was possible to have a good quality base able to withstand without difficulties the weight of the future barrier.

The construction commenced in December 2004, and was completed, with some small interruption due to bad weather conditions, in three months.

The barrier was constructed using the wrap around technique; considering the small inclination (45°) and the nature of the soil, cohesive, no sacrificial formwork was necessary. A phase of the construction is shown in Fig. 5.

A comparison between the existing situation before the construction of the barrier and the final situation is shown in Fig. 6, where also the soil modelling that has been done in the upper part of the area is clearly visible.

Figure 5. downstream side of the barrier during the construction.

4 CONCLUSIONS

A protective system from mudflows is a structure that should have a good flexibility, even if it should be able to withstand important thrust. The use of a geogrid reinforced barrier is an effective solution, both in terms of capacity to resist the thrust, and in terms of cost of the work. Any other type of rigid barrier could not be used, considering first of all the cost of the structure, even in terms of environmental impact. The possibility to use the locally available fill material through the use of a special type of reinforcement made this solution particularly effective. There was not need to bring in good quality fill by road, or to dispose of the poor quality material already on site.

Figure 6. Comparison between the original situation and the situation at the end of the work.

The solution proposed was absolutely innovative for Italy, and can be considered as an effective solution for mudflows problems worldwide.

REFERENCES

Cancelli, A., Cancelli, P., Cazzuffi, D. and Rimoldi, P. (2000). "The use of Geosynthetics in Hydraulic Works." Proceedings 2nd International Conference on New Trends in Water and Environmental Engineering for Safety and Life: Eco-compatible Solutions for Aquatic Environments. Capri (Italy) July, 3-7 2000.

Peila D., Castiglia C., Oggeri C., Guasti G., Recalcati P. and Sassudelli F. (2000) "Full scale tests on geogrid reinforced embankments for rock fall protection." Proceedings EuroGeo, Second European Geosynthetics Conference and Exhibition, 2000, Bologna.