Two major geogrid reinforced rockfall barriers in northern Italy

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ABSTRACT: The paper describes two interesting examples of geogrid reinforced rockfall barriers designed and constructed in Italy, in the Alps region close to the France border.
In the first example the barrier was created to protect the Regional road 47 linking the city of Aosta with the town of Cogne, that in 2006 was interested by a series of landslides and rockfalls that were representing a danger for the traffic passing along the road.
A geogrid reinforced embankment, 340 m long and 2.50 m wide at crest was constructed. The upstream side of the barrier was about 7.00 m high, while the downstream side was over 13.00 m high.
To intercept smaller boulder that could pass at a greater height, a metallic barrier 3.00 m high was fixed to the crest of the embankment. The paper describes the design approach, the analysis done, the study that has been done to guarantee a proper collection and drainage to the runoff water. The system of drainage geocomposites and trenches intercepting the water coming from the upstream side, passing through the embankment and discharged downstream in steel culvert is described. In order to evaluate the effectiveness of the anchorage system of the metallic barrier fixed on the top of the reinforced soil barrier, destructive pull-out tests on the anchorage were performed and the results are described in the paper.
In the second example the techniques for maintenance and repair of geogrid reinforced barriers, designed and constructed a few kilometres from the previous one over 5 years ago and subjected to a major rockfall event is described. The boulders falling over two different barriers were over 30 m^3. The barriers were suffering no significant damage and were easily repaired after removal of the boulders themselves. The back calculation of the energy of the boulders impacting over the barriers, as well as the repair procedures are described.

1 INTRODUCTION

Rockfall are usually regarded as a part of the more widely defined category of Fast Slope Movements.

Due to their impact on human lives and to the difficulties related to their prediction, these phenomena are commonly considered to be among the most dangerous slope movements. The difficulties in providing a proper and safe design are related to the uncertainties in any of the design phases: triggering (with the evaluation of the point from which rock boulder can detach, their shape and dimension, their initial trajectory), dynamic (considering rebounds, sliding, impact with trees, change in the dimension and shape of the boulder) and interaction (impact) with containment structures such as barriers or embankments.

Whenever the geometry of the area allows it, the use of earth embankments allows to absorb high energies, providing long term efficiency with no or very low maintenance costs and with a high efficiency even in case of stone swarms. An important reduction of the area necessary to construct the barrier is given by the use of geosynthetics reinforced barrier; such technology allows also the following advantages to be obtained: first of all the ground is "tied" by the geosynthetic; this increases the resistance of the structure. Geosynthetics have an elastic-plastic behaviour; they quickly react to applied loads with an increase in the elastic modulus; in the case of short term loads (impact), creep phenomenon does not occur. Finally, properly selected geosynthetics increase the dynamic dumping characteristics of the reinforced soil compared to soil on its own (Carotti and Rimoldi, 1998).

There are few analytical procedures that allow a designer to evaluate the effects caused by the impact of a rock mass over a soil structure. These methods, anyway, are characterised by some difficulties in defining the correct required variables. An important development in the study of reinforced soil structures are the studies made in the last years on HDPE geogrid reinforced rockfall (Peila et al, 2000; Recalcati et al., 2001).

Full scale impact tests have been performed with concrete blocks having a weight of about 4.500 kg and 8.800 kg. The impact energy measured were about 3.000 kJ and 4.500 kJ.

Even under such impact the ground wall not pierced and the occurred deformations did not cause any structural collapse.

2 OZEIN PROJECT

An interesting example of geogrid reinforced embankment coupled with a conventional steel barrier had been designed and constructed in Aosta area, in Northern Italy, close to the French border.

The area interested by the project was subjected to an important series of landslides and rockfalls; the last of these events was occurring in 2006, when over 150 m^3 of rocks were interested by toppling phenomena, with boulders having dimensions ranging between 0.50 m^3 and 10 m^3. Two big boulders, respectively 8.00 m^3 and 10 m^3 were reaching reaching the Regional road 47 connecting the Mont Blanc highway with the town of Cogne.

The protection structure designed was consisting in an embankment reinforced with extruded HDPE geogrids (Table 1), with faces inclined at 70°, using wrap around technique with steel mesh formworks at the face. The barrier was 340 m long with a maximum height downstream up to 16.00 m and a maximum height upstream of 7.00 m; the width at the crest was kept equal to 2.50 m in order to allow the subsequent installation of a 3.00 m high steel mesh barrier, capable to absorb a maximum energy of 2000 kJ (Fig. 1 and 2).

Table 1: mechanical and physical properties of the geogrids.

Properties	Value	Test method
Polymer type	HDPE	
Structure	Mono-oriented Extruded	
Unit weight	320, 420 and 600 g/m²	ISO 9864
Peak tensile strength	45, 60 and 90 kN/m	EN ISO 10319
Allowable design strength	18.5, 24.6 and 36.9 kN/m	EN ISO 13431

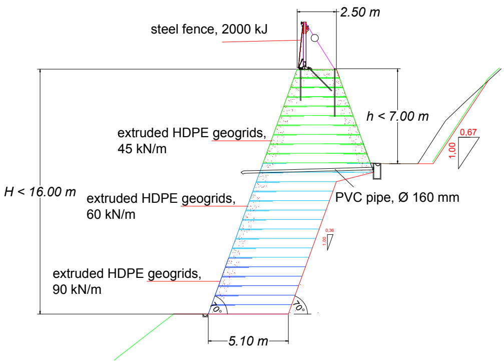

Fig. 1: cross section of the geogrid reinforced barrier

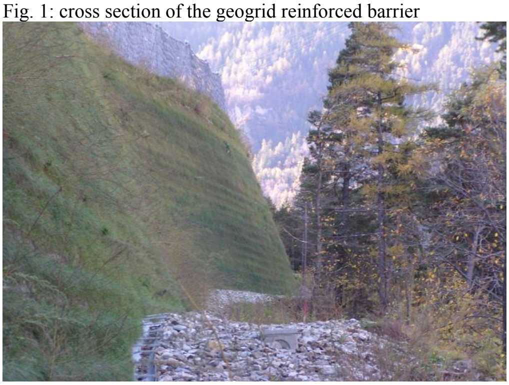
Fig. 2: downstream picture of the barrier

The construction of a soil embankment acts as a dam capable to stop or divert the superficial runoff. This could lead to possible problems in case of heavy rainfall; an accurate drainage systems was then designed and constructed. At the base of the whole upstream side of the barrier a stainless steel gutter was laid; drainage of the water was ensured through drainage geocomposites laid at 20 m interval along the excavations surface. The water collected was reaching the downstream face in stainless steel ditches at the base of the downstream face (Fig. 3).


Fig. 3: steel gutters and collection boxes - downstream face.

The design and construction of the steel barrier on top too was extremely challenging. Clearly a conventional steel barrier with ropes connected to the upstream side was not feasible, as the distance between the top of the embankment and the slope was excessive. A system with anchorages and brakes directly laying on the crest of the embankment was necessary. Several systems with such a fixing device exist; however, the efficiency of the anchorage system is something that needs to be tested and proven, as the anchorage bars or ropes are inserted in a "reconstructed" soil and not in a natural soil. To verify the efficiency of those anchorage a full scale pull-out test was decided. Both a steel bar, 32 mm diameter and 6.00 m long, grouted and a steel rope with the same length and grouted were showing a pull-out resistance well exceeding three tons, although the test was done in a position very close to the face of the embankment. Those tests were giving adequate guarantees that the complete system (geogrid reinforced barrier and steel barrier) could guarantee the required protection.

Fig. 4: Installation of the steel fence on top.

3 RHEMES PROJECT

Although the estimation of the possible impact energy and then the design of a rockfall barrier can be rather easily be done, and although full scale tests can prove the efficiency of both reinforced soil embankments and steel fences, still usually there can be some doubts about the real behaviour of a real barrier.

As said before, estimation of the size, shape end point of detachment of the boulder can be done, but then foreseeing what can happen during the fall is difficult. There is then a clear understanding that soil barrier can withstand energies much higher than the ones tested up to now (as said before, 4500 kJ), as well as there is a clear understanding that the current design method are underestimating the resistance of the barrier. Still, there are not clear proofs about the real limit of such structures. Another objection that sometimes is raised against the use of soil barrier is the possible repairing system after an impact.

A dramatic event was occurring on a site not far from the previously described. In this site a series of 4 barriers, constructed with exactly the same type of geogrids and with a geometry similar to the one here described were designed and constructed between 2001 and 2002. The analysis of the site, already interested by rockfall events damaging a 15 kV electric line and a local road and almost hitting the small town of Rhemes, was showing the presence of an area from which boulder could be detached about 500 m above the road and the electric line to be protected.

The analysis of the size and dimension of the previously felt and of the possible future boulders was showing a high percentage of rocks smaller than 6 m^3, but also fewer blocks (2% on the total amount) with dimension up to 15-16 m^3. The analysis of the possible trajectories for the smaller boulder were giving as a maximum impact energy a value of 4000 kJ, value covered without problems by the test and the certifications of the rockfall barriers used. Barriers were built between 2002 and 2003 (Fig. 5).

Fig. 5: Construction of the barriers at Rhemes.

Unfortunately, during an event occurring in 2008, among some smaller boulder two big boulders, respectively 35 m^3 (Fig. 6) and 30 m^3 (Fig. 7) were falling from an area slightly below the expected one (altitude 1900 m) and after a trajectory that nobody could witness, were reaching the position of the barrier hitting the same.

Fig. 6: Boulder, 35 m^3, reaching the lower level of barriers.

Fig. 7: Boulder, 30 m^3, reaching the upper level of barriers.

During an inspection of the site a few days after the event it was possible to verify that the impact was causing minor damages to the structures and that they were still capable to resist further impacts without need to provide important repairs.

Once it was clear that the road, the electric line and the town were safe, it was possible starting to define a remediation system, and it was possible to try to run a sort of back-analysis of the event to try to guess the possible type of energy to which the barrier were subjected. With a simple calculation based on the transformation of the potential energy into kinetic energy (without dissipations) considering the masses of the two boulders (79 and 92 tons) and the difference in altitude (355 m for the barrier hit by the 35 m^3 rock and 310 m for the other one), this was leading to unrealistic values of both the impact velocity and the kinetic energy (83 m/sec, 276,000 kJ and 78 m/sec, 241,000 kJ). Obviously the no-dissipation assumption is not realistic. A sensible hypothesis on the reduction of the velocity due to rebounds, impact against trees or other rocks cold be done; assuming that the speed at the moment of the impact is 20% the one obtained before (around 16 m/sec for both cases), we have impact energies of 11,000 and 9,600 kJ, that seem to be absolutely realistic.

As said before, these event were a good opportunity to define a possible remediation system after the impacts. As said before, the damage was minor and the maximum excavation depth was limited to 200-300 mm; in these situations it is necessary to prevent the washout of the soil from the area where both the geogrid at the face and the vegetation are missing, and where the geometry can be overhanging. In this situation it is necessary to fill the holes with soil, compacting it as much as possible, for example with the backhoe; for the upper part, where overhanging can occur, it can be necessary using a new steel mesh formwork at the face with a geogrid inside as a formwork to keep the soil in place. The finished surface should be protected from erosion during the period between the end of the work and the growth of the grass, for example by using geomats or biomats, or hydroseeding the face.

Fig. 8: Repair of the upper barrier.

4 CONCLUSIONS

Geogrid reinforced embankment represent a very effective and safe solution against rockfall. The use of this technology allows to create structure capable to withstand energies greater than any other type of barriers. Many of the problems that could be encountered with these systems, such as drainage, maintenance and repair) can be simply solved. It is important to notice the fact that these barriers can be constructed with other structures, such as steel barriers, at the crest, thus increasing the performance of the system through.

It would be important to improve the research in the filed of soil barrier, for example through tests performed at higher energies (at least up to 6.000 kJ), to increase the knowledge of the mechanisms involved and to give designers and authorities new instruments to evaluate the possible protection solutions.

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