Full scale tests on geogrid reinforced embankments for rock fall protection

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ABSTRACT: Geogrid reinforced embankments can absorb high quantity of dynamic energy, both from cyclic loads and from impulsive loads, with high resiliency and limited deformation. This property finds a positive application as a barrier to rocks fall, for the protection of towns, roads and plants. An experimental program was performed in a specific testing facility, where concrete blocks of up to 9 tons of weight can be driven onto a geogrid reinforced embankment at a speed in excess of 30m/s, producing impacts with more than 4000 kJ of energy. Several instrumented embankments with different geogrid strengths and layout were tested under strictly controlled conditions, allowing to draw a quantitative assessment of the limit impact resistance of these structures.
The paper provides a full description of the experimental set up, of the different tests performed, and of the obtained results.

1 INTRODUCTION.

The need of protecting inhabited areas against the fall of stones has led to the development and use of both numerous and different types of technological solutions (to prevent the blocks from breaking off the rock walls) and passive types (to control, intercept or deviate the blocks during movement). Among the other passive type structures, recourse has been made, over the last ten years, to the use of reinforced ground walls in particular in those areas where the detachment of blocks is foreseen of volumes or velocities great enough to break through the maximum resistance of traditional wire netting rock protection barriers (Lazzari et al., 1996).
Apart from the better performance, in terms of protection efficiency, among the advantages that a ground wall can present in comparison to a high-energy absorption wire netting, mention can be made of:

- the efficiency of the protection, even in the case of repeated collapses along the same slope section;
- reduced maintenance;
- reduced environmental impact (in particular if the protection work is masked with adequate naturalistic engineering interventions);
- The negative aspects that can be mentioned are:
- the need of occupying a vast strip of land as the base of the barrier which increases as the height of the barrier increases. This problem can in part be mitigated through the use of reinforced soil;
- the presence of soil with planimetrical and altimetrical characteristics that are suitable for the construction of the ground wall.

Whenever geogrids are used as reinforcing elements of a ground wall, these allow the following advantages to be obtained:

- the ground is "tied" by the geogrid both in the longitudinal and transversal directions of the ground wall thus in-creasing the resistance of the impact structure;
- HDPE geogrids have an elastic-plastic behavior so that they quickly react to applied loads with an increase in the elastic modulus; furthermore, in the case of short term loads, as in the case of an impact, creep phenomenon does not occur, therefore the whole resistance to traction of the geogrid can be mobilized;
- geogrids allow an increase of the dynamic dumping characteristics of the reinforced soil compared to soil on its own, both through the energy that is directly absorbed by the geogrid itself and through the "Coulomb dumping", due to friction generated in the dynamic stage (Carotti and Rimoldi, 1998).

On the other hand, it should be noted that the designing regulations for reinforced ground walls subject to dynamic impact are still rather vague as very few specific researches on the subject are available in literature. The latter is therefore the specific aim of this research. The only proposed analytical procedure, to the authors knowledge, derived from Kar's experience on the evaluation of the effects caused by the impact of projectiles on buried structures, provides a calculation of the depth of penetration of the rock mass inside the ground wall, in such a way as to be able to estimate the effective possibility of perforation of the defense mechanism due to serious impacts (Paronuzzi, 1989).

2 PREVIOUS FULL SCALE TESTS ON GROUND WALLS

Full scale tests were carried out in Denver (Burroughs et al., 1993) and in Japan (Yoshida, 1998). In the case presented by Burroughs et al. (1993) 18 tests were carried out with velocities that varied from a minimum of 5.5 m/s to a maximum of 19.2 m/s and weights from a minimum of 1.9 kN to maximum of 81.7 kN. The mass that produced the most damage to the structure, which was constructed with a height of 3 m and a thickness of 2 m, had an energy of 1436 kJ and the deformations were of an order 0.9 m on the upper face and about 0.7 on the lower side. The device was built with mixed granular soil, reinforced with geotextiles, spaced in 0.30 m layers, with wooden containment faces (thickness 0.15 m) to make the measurement of the deformations easier.

In the case presented by Yoshida (1998), the test was carried out by making a rock block rotate down a very steep slope from a height of 40 m against a reinforced ground wall on whose up-per side two geotextile bags were arranged (0.5 m and 0.8 m in diameter respectively) and whose final dimensions were there-fore 5.3 m wide at the base and 3.3 m wide at the top with a height of 4 m.

The test block had a mass of 17700 kg and an impact energy of about 3000 kJ. The impact caused relevant damage even though it stopped the block.

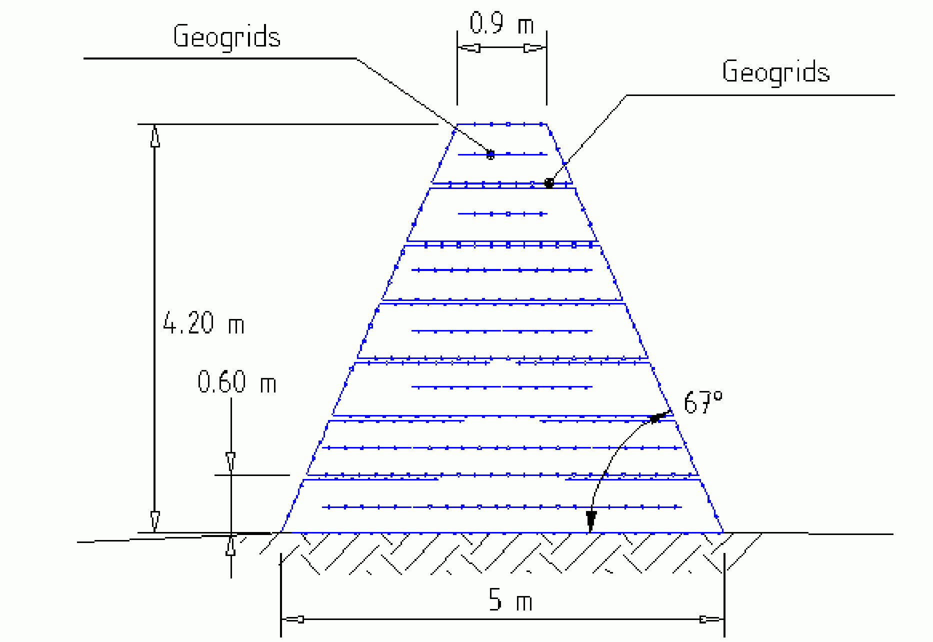

Fig. 1: Scheme of the tested earth wall.

3 CARRIED OUT TESTS.

3.1 *The first test ground wall*

The test ground wall (Fig. 1) was specifically designed for the impact test with isosceles section of 4.20 m in height, the upper base was of about 1.00 m and the lower base about 5.00 m. The inclination of the faces was kept equal on the two sides even though in reality normally used reinforced ground walls are less steep towards the valley, basically for aesthetic reasons.

For details on the designing procedures of reinforced ground walls reference can be made to technical literature (Rimoldi, 1987, Jewell, 1991). The choice of constructing a steep isosceles ground wall leads to a reduction of the soil mass that will oppose the impact and therefore allows the setting up of a particularly critical test for the structure.

The filling soil, found on the site, is made up of weathered limestone material with granulometry of gravel (56.6%) and of sand (23.4%) with the presence of silts and clays (19%).

Laboratory tests on the materials furnished an drained cohesion of 9 KPa and an drained internal friction angle of 33.7°. The in situ density, verified through a compaction test, resulted to be equal to 21.1 kN/m3; such a value, compared with the optimum AASHTO Modified test, furnishes a density of 94%.

The reinforcement elements are made up of geogrids in High-Density Tenax TT 050 Samp polythene and its main technical characteristics are given in Table 1.

Parameter	*Value*	
2% ELONGATION RESISTENCE	11.0	KN/m
5% ELONGATION RESISTENCE	25.0	KN/M
MAXIMUM TENSILE STRESS	50.0	KN/M
YIELDING STRAIN	11.5	%
LONG TERM DESIGN RESISTENCE	19.0	KN/M

Such geogrids are 100% HDPE extrusion produced, have high mechanical resistance and remarkable chemical, physical and biological inertia and are stabilized to the action of UV rays thanks to lampblack. They are also made up of a plane monolithic structure with a regular elongated opening distribution, which shows longitudinal and transversal threads.

Table 1: Properties of the Geogrid TENAX TT50SAMP.

During production the longitudinal threads of the geogrids undergo a molecular orientating process to increase the mechanical characteristics and ensure a high resistance in the long term. The joints between the longitudinal and transversal threads are in part integrated by the geogrid structure, without connection or sewing.

The test was performed in the Meano test site (Trento) (Fig.2) which was specifically set up to carry out full-scale tests for rein-forced ground walls (Peila, 1999; Peila et al. 1999; Rimoldi et al. 1999).

The movement of the smoothed edged cubic shaped block, weighting 4998 kg, was recorded before and during the impact through a system of Beta video cameras with a time code display and a 25 photograms/s taking speed. The deformations on the upper and lower faces were obtained after the impact as were those on the inside of the mass of soil (for this purpose, colored reference network was set up inside the ground wall).

Figure 4 shows the construction stages of the earth wall.

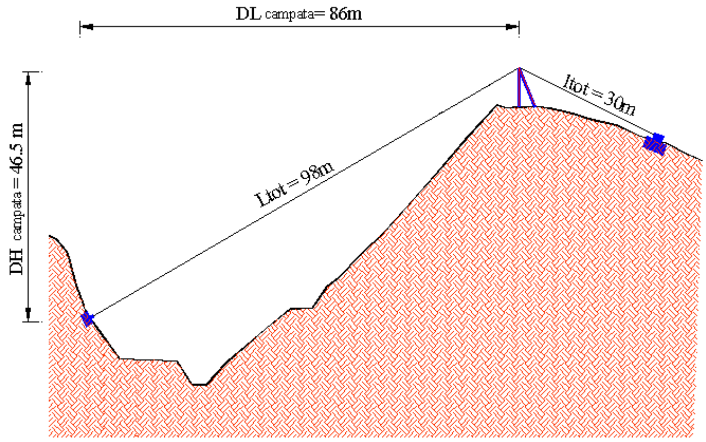

Fig. 2: Scheme of the test site.

Fig. 3: The block impacting the front face during the first test.

3.1.1 *Experimental results of the first test*

The evaluation of the kinetic impact energy was carried out by analyzing the photograms of the film taken during the event, which were taken from three different angles (as an example Fig 3 shows the moment of impact of the block against the ground wall).

Fig. 4: Construction phases of the ground wall.

Fig. 5 instead shows the trajectory of the block whose translational velocity, at the moment of the impact, was estimated as 31.73 m/s, therefore the kinetic energy of the block at the moment of contact is about 2511 kJ.

The ground wall was neither pierced nor damaged in an irreparable way. On the front side a crater formed with a maxi-mum depth of about 0.60 m while on the backside an extrusion of soil could be observed (Fig.6). No significant variations of the geometry of the ground wall could be observed outside the area directly involved in the impact.

The impact occurred in a high portion of the ground wall, where the transversal thickness was about 1.2 m. The maximum measured displacement on the lower side was of the order of 0.23 m and it was concentrated or rather confined by the reinforcements on the two sides of the wall involved in the impact.

The velocity and acceleration measurements in the longitudinal (direction of the fall of the mass), transversal (along the wall) and vertical directions permitted the observation of the almost total dumping of the velocity and acceleration in the transversal direction.

After the test, the ground wall was dug and the internal de-formations were revealed where possible by the colored reference grid. A tension crack was observed which began 0.60 m below the top and which spread on the inside downward with a geometry that seemed to follow the shape of the mass. In the up-per zone (0.30 m below the top), no visible dislocation of the soil was observed but it is however possible to show the passage between the stressed and compressed areas. In the maximum opening position, the tension crack has a width of about 140 mm (comparable, as order of size, with the extrusion below the ground wall). No geogrid appeared to be broken.

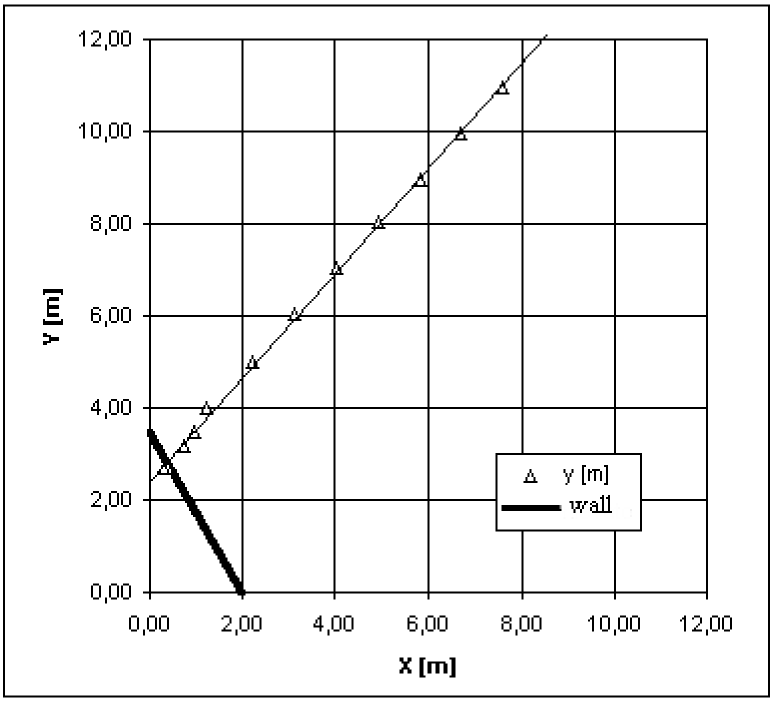

Fig. 5: Trajectory of the barycentre of the block in the first test.

3.2 *The second test ground wall*

The second test ground wall has been built following the same design pattern of the first one, but geogrids in High-Density Tenax TT 045 Samp have been used as reinforcements.
The same filling soil of the previous test has been used as well, with an in situ density of 22.3 kN/m3 and dry weight of 1.83 kN/m3.

Fig. 6: Deformation of the wall due to the impact.

The movement of the smoothed edged cubic shaped block, weighting about 8778 kg was recorded before and during the impact through a system of Beta video cameras. The deformations on the upper and lower faces were obtained (for this purpose, several references were disposed).

3.2.1 *Experimental results of the second test*

Translational velocity of the boulder at the moment of the impact was estimated as 31.3 m/s, therefore the kinetic energy of the block at the moment of contact is about 4354 kJ (Fig.7).

The ground wall not pierced and the occurred deformations did not cause any structural collapse. On the front side a crater formed with a maximum depth of about 1 m while on the back-side a large displacement of soil (about 0.90 m) could be observed. The geogrids have occasionally been thorn, as shown in fig.8, but the global stability of the structure appeared to be assured anyway.

The global behavior of the earth wall showed a major influence of the geogrid interfaces, which allowed a relative sliding of the levels solicited by the impact (Fig.9).

Two more crash tests, each one developing about 4300 kJ, have been carried out on the same wall and in the same impact conditions (speed, boulder size and trajectory) without repairing the structure after every impact. It was shown that such a barrier can stop up to three high energy boulders before collapsing be-cause of yielding of reinforcement and massive loss of compaction in the soil medium.

Fig. 7: Two frames showing the 8778 kg block while being arrested by the wall during the second test.

Fig. 8: Thorn grids in the second test.

Fig. 9:Views of front and back deformations after the first impact in the 4354 kJ test.

4 CONCLUSIONS

According to the results obtained from the experiments the following considerations can be made:

- the tests allowed to study the behavior of the structure till an energy of about 4200 kJ that corresponds to the maximum energy level that has so far been experimented with reinforced ground walls. In both the tests the structure though having been solicited in the upper part was not pierced but remained operative and therefore able to take further impacts;
- in the first test the analysis of the permanent damage inside of the reinforced ground wall and of the position of the tension crack has led to the identification of the separation surfaces between the stressed zone which would seem to justify the hypothesis that the energy spread or-

thogonaly to the face of the mass during the impact. The same concept can be applied to the position of the thorn geogrids observed after the second test;

- in the first test, a detailed examination of the video films has shown a recall movement of the lower face after a maximum deformation (not measurable). This effect can surely be attributed to the presence and action of the geogrids. Such a recall effect, and also the observation of the existence of a tension crack, allows one to affirm that, in the absence of geogrids, the ground wall would have been pierced or at least that the part of the tension crack on the lower side would have collapsed on this side;
- the analytical methods commonly used for static de-sign of ground walls are not completely ef-ficient for a dynamic analysis of the phenomenon,, so a more de-tailed study, also based on numerical methods, must be carried out;

In conclusion, the proposed test procedure has shown to be efficient in the evaluation of the behav-ior of the rock fall defense structure and it should be always used to define the in situ response of the a ground wall since it is not possible to use real scale experiments when the structure is in-stalled in a site to be protected. Only with these tests it is possible to obtain all those data needed by numerical models to calibrate the geotechnical parameters and provide a realistic design aid.
Directly referring to the carried out experiments it can be concluded that both tests have shown a good behavior of the reinforced earth walls even under impact energies that cannot be dissipated by commercial net fences so, where the morphology of the place allows it, a re-greened reinforced ground wall can present numerous advantages such as the capacity of being well inserted into the environment and the possibility of facing high impact energy.

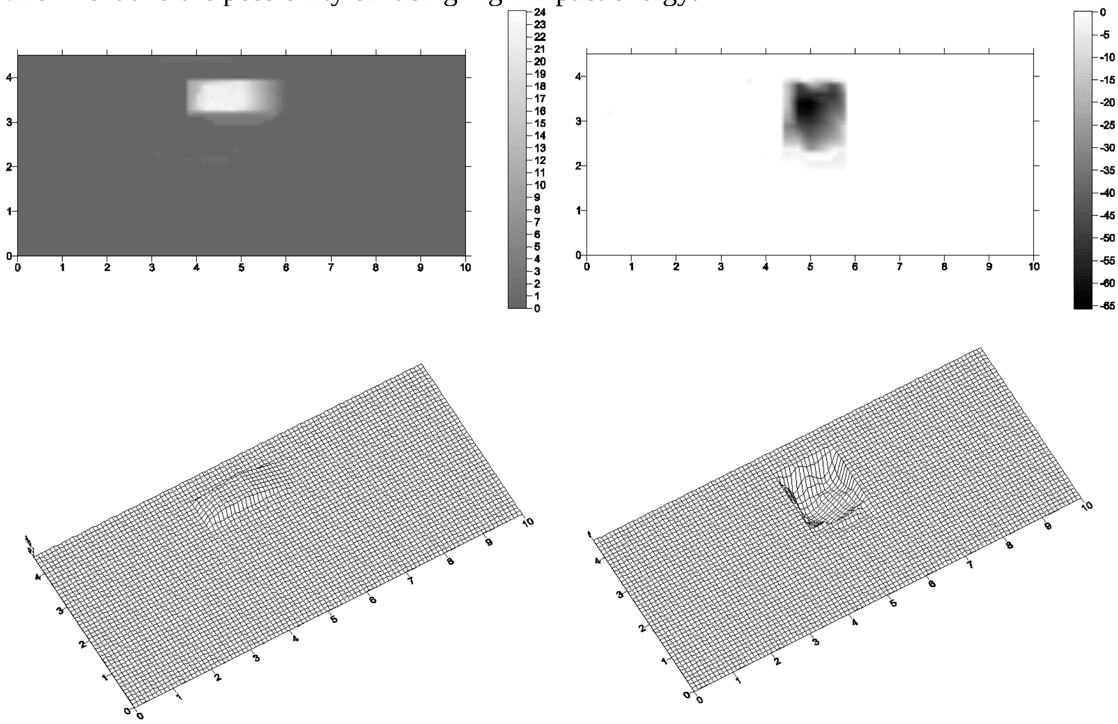

Fig. 10:Displacements of the front and back faces after the 2500 kJ test (depth scale has been altered).

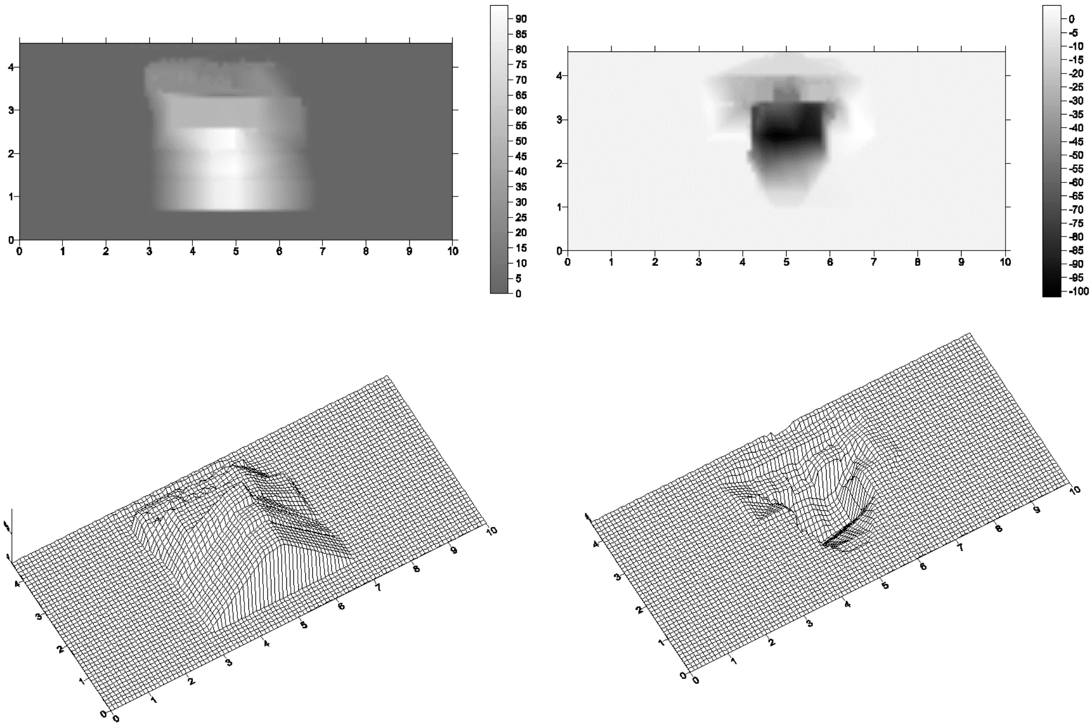

Fig. 11: Displacements of the front and back faces after the first impact of the 4354 kJ test (depth scale has been altered).

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