Experimental investigation of the dissipative efficiency of a multilayered protective structure against rockfall

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ABSTRACT

An experimental investigation is carried out to study a new wall-type protective structure against rockfall. The dissipative process takes place in two steps: first, the localized impact force is distributed on a larger surface by means of a concrete slab and then the distributed force is dissipated within a layer made of granular material.

The aim of the experimental study is to compare the dissipative effect of several granular materials and different configurations with an impact test. A steel ball is dropped from a certain height and the transmitted impact force on the structure is measured. Granular materials such as Hostun sand, gravel and pozzolana are tested. The conclusions of the measurements are that the dissipative effect of the sand or gravel is better than that of the pozzolana.

Finally, the dissipative effect is measured on a concrete layer overlaid with geotextile socks filled with sand.

KEYWORDS: protective structure, rockfall, impact, small scale experiments.

INTRODUCTION

Passive protections against rockfall are commonly, either barriers for low impact energy (up to 50 kJ) [Heierli et al. 1981], embankments for stronger energy (between 10000 and 50000 kJ) [Descoeudres et al. 1999], or anti-breakup safety nets for an intermediate energy range (10
to 3000 kJ). Theses structures stop rockfall by transferring kinetic energy to elastic and plastic deformation.

This paper deals with dissipative effects and the aim is to contribute to a new concept of wall-type multilayered structures. The dissipative process takes place in two steps: first, the concrete slab under impact will spread the load on the granular layer and dissipate energy with the plastic deformation of the reinforcement steel bar [Perrotin, 2002] [Mougin, 2005] and then the deformation in a granular material such as sand will dissipate kinetic energy [Montani, 1998] (Fig. 1).

![Figure 1: Multilayered structure](image1)

In order to study this multilayered structure, small scale experimental impacts tests are carried out. The aim is to classify the dissipative capacities of different materials and to study the effect of a rigid impacted layer on a granular material. In this first step in the design of a new protective structure, the experimental setup is horizontal whereas the real case is vertical however this is possible because the effects of gravity are minimum in this setup.

![Figure 2: Concrete slab impacted.](image2)
The impact tests will take into account:

- Granular materials, such as sand, gravel and pozzolana to test the dissipative effect.
- Composite structures made of geotextile with or without a concrete slab submitted by impact load (Fig. 2).

IMPACT EXPERIMENTS

Materials and composite structures

In the first experimental investigation the following materials are tested in terms of their dissipative effects:

- The first granular studied material is sand. It is already used as damping material to protect reinforced concrete structure. Some tests in the EPFL laboratory have shown the dissipative effect of a sand layer [Montani & al., 1996].
- The second material is gravel. It will be compared with sand to study the granulometry effect.
- The third is pozzolana because of its physical properties. This material has a great porosity, so that it has a great capacity to be crushed.

Then the effect of confinement with geotextiles filled with granular materials is tested and finally the repartition effects on a concrete slab are studied. To do so, a concrete slab overlays geotextile socks filled with sand. A similar setup has been used in Japan to build embankments where the socks are filled with sand or macadam (Fig. 3).

Figure 3: GEO ROCK WALL

Experimental set-up

In the impact tests a steel ball is dropped from a measured height and the transmitted impact force on the structure is recorded (Fig. 4).
The support is made of a 50 cm wide steel plate with a 1 cm thickness which lies over a 5 cm thick reinforced concrete slab. The impact force is measured with a load sensor. Its position is on the center of the support. The studied protective structure is contained in a 30 cm high wood case, which rests on the sensor (Fig. 4).

The mechanical link between the wood case and the sensor is not a threaded metal stem, thus only the compressive load can be measured. As there is one sensor in the center, a PVC pipe guides the steel ball. Hence the impact is centered and on top of the sensor.

The diameter of the steel ball is 15 cm and its mass is 13.6 kg. With this set up, the controlled parameters are the following:

- Drop height: 0 to 4 m
- Steel ball mass: 13.6 kg
- Material thickness: 10 to 15 cm
- Materials: sand, gravel, pozzolana, geotextile socks, concrete slab.

**Measurement system**

Several tests are carried out for the same drop height to compare impact loads for different configurations. The relative values of the dissipation are determined with this step. In fact, the lower the transmitted load, the larger the dissipation effect which is recorded. So, the impact forces can be classified to compare the dissipation effect of materials. Moreover, if the impact load is known, structure dimensioning can be carried out.

These impact loads are measured with a fast acquisition. In Montani thesis [MONTANI, 1998], the impact characteristic times are on average 40 ms. For our device, impact load versus time is recorded on a computer with the labview software.
To compare dissipation effect in different materials, a dynamical amplification factor $A$ is used. It is the ratio between the dynamical force and the static force of the steel ball:

$$A = \frac{F_{dyn}}{F_{stat}} = \frac{F_p - F_i}{F_f - F_i}$$

**RESULTS**

First, results of the dissipation capacity of granular materials such as sand, gravel, and pozzolana are shown. Next, composite configurations will be studied. Confinement effect with geotextile and load spreading with a concrete slab will be exposed.

**Granular materials**

*Sand impact tests*

The used sand is Hostun sand. The granular size is 0.1 to 1 mm.
Sand has been tested for different drop heights and two thicknesses. Figure 6 confirms that the transmitted load from the material increases if the drop height increases too. In addition, the smaller the sand thickness the more the load is transmitted from the layer to the sensor. For a 10 cm thickness and a 2 m drop height, the amplification ratio is 55 and for 15 cm, it is 45. These results are the reference for all the following comparisons with other materials and other configurations.

<table>
<thead>
<tr>
<th>Drop height (m)</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic energy (J)</td>
<td>70</td>
<td>135</td>
<td>205</td>
<td>270</td>
<td>340</td>
</tr>
<tr>
<td>Thickness sand=10cm (kN)</td>
<td>2.3</td>
<td>3.8</td>
<td>5.5</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>Thickness sand =15 cm (kN)</td>
<td>1.6</td>
<td>3.3</td>
<td>4.6</td>
<td>6.2</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Table 1: sand impact load versus drop height

**gravel impact tests**

The granular size of the gravel used for impact tests is 5 to 15 mm. One thickness of 15 cm is tested for several drop heights.

![Gravel-sand comparison](image)

Figure 7: gravel-sand comparison

The transmitted loads by gravel or sand are similar. We can notice that gravel values are more dispersed than sand values.

**Pozzolana test impact**

Pozzolana is a volcanic rock, porous and abrasive. Its dry density is less than 1 and the granular size is 7 to 12 mm for our experiment.

The aim of the impact tests is to compare the dissipation effect of the pozzolana with sand. As the density of these two materials is not the same, they can be compared for the same mass or for the same volume. The density ratio between sand and pozzolana is 1.5.
Responses comparison between pozzolana and sand for the same volume (Fig. 8):
For 10 and 15 cm thicknesses, the dissipation of pozzolana is smaller than the dissipation of sand. With a 15 cm thickness and a 2 m drop height, the amplification ratio is 45 for the sand and 55 for the pozzolana. In the other hand, the evolution of the force as a function of drop height is the same for the two materials.
For the same volume, pozzolana dissipates impact load less than sand.

Responses comparison between pozzolana and sand for the same mass (Fig. 8):
To compare pozzolana and sand effect for the same mass, a 15 cm thickness of pozzolana must be compared with a 10 cm thickness of sand. Figure 8 shows that the impact load values for a drop height are the same for the two materials. For a 2 m drop height, the amplification ratio is 55.
For the same mass, pozzolana dissipates the kinetic energy like sand.

After these first tests and for an energy range of 400 J, the advantages related to the use of pozzolana are not shown. For higher kinetic energies, the results should be the same because evidence of crushing is already seen during these low energy impact tests. Finally, pozzolana dissipates the impact load less than sand.
Transmitted impact force | drop height | material thickness  
---|---|---
Sand | |  
Pozzolana | |  

Table 3: load evolution in tested granular materials

Composite structures

Confined pozzolana with geotextile

In the previous cases the granular material was tested without confinement. For each test, the penetration of the steel ball is at least half its diameter. Now, the granular material is confined within a geotextile pocket.

A first test is carried out with pozzolana for a 0.5 m drop height. The impact force is very strong even if the drop height is small. The ratio of the peak force for the confined pozzolana with respect to the unconfined case is 4. Finally, the geotextile stops the penetration of the steel ball and the impact force is better transmitted than in the case of pozzolana without geotextile. We can notice that the impact time of confined pozzolana is smaller than a pozzolana without confinement (Fig. 9). In fact, the geotextile decreases the penetration depth of the steel ball and allows a better load transmission.

![Figure 9: geotextile effect on response time](image)

The impact times for the material without confinement are 40 ms and 25 ms for a confined material (Fig. 9). The drawback of using a single large pocket containing the granular material is that the displacement between grains decreases inducing a better transfer of the elastic energy. Thus, to overcome this problem while still using geotextile containers, narrow geotextile socks are loosely arranged in order to produce a larger deformation of the dissipative layer.

Concrete slab with geotextile socks filled with sand

To decrease the transmission of the impact force, the granular material must be greatly deformed. For this purpose, the sand will be contained in geotextile extensible socks arranged in a loose manner. In Japan, socks are already used for embankments (Fig. 3). The diameter of the extensible geotextile increases from 50 to 120 mm and the length is 50 cm. The socks are filled with 1 liter of sand.

For the first test, 4 layers with 5 socks with a half diameter space are tested. The layers are perpendicular to one another to allow a large deformation during impact (Fig. 10).
These socks are not impacted directly because a concrete slab is laid on them for protection. Eventually this slab will dissipate a part of the energy by damaging, but mainly its role is to spread the load over the socks.

Different configurations are tested:

First, like the previous impact tests different drop heights were tested with different numbers of layer of socks. Second, the concrete slab has been replaced by a wooden plate in some tests in order to study its contribution. Third, the socks are directly impacted to appreciate the effect of a slab. Fourth, a 15 cm unconfined sand layer is tested to compare its contribution versus 2 layers of sock (same global thickness).

**Figure 11 : socks and concrete slab effect for 1 m drop height**

**geotextile socks effect:**

- The transmitted impact force is strongly influenced by the number of layers. For a 1 m drop height, the amplification factor $A$ is 90 for 2 two layers and 40 for 4 layers (Fig. 11).
- If the sand is simply confined between impacted slab and the edges of the wooden case (case of the unconfined sand layer), the impact load is almost directly transmitted from the slab to the sensor through the sand layer because the frictional displacements between
grains are small. For 1 m drop height, the amplification ratio is 80 without geotextile socks and 40 with them (Fig. 11).

**Concrete slab effect:**

Only concrete slabs without steel reinforcement bars were used. When broken, a cone is observed directly under the impact point as shown in Fig. 12. These failures are probably due to the effects of transverse shearing. This mechanism is frequently observed during impact test, even on a reinforced concrete slab, for rockfall [MOUGIN, 2005] or for missile impact [YANKELEVSKY, 1997].

![Figure 12: impacted concrete slab and cone views](image)

- When the concrete slab is replaced by a wooden slab, the measurement of the impact force for 1 m drop height is the same for the concrete slab and the wooden plate. Despite the fact that the concrete slab breaks, it seems that the kinetic energy is not dissipated by the failures in the concrete. However, using a reinforced concrete slab, which was not the case here, would dissipate the impact energy more through the plastic deformation of the steel reinforcement bars [MOUGIN, 2005].
- Impacting directly the geotextile socks amplifies the transmitted impact loading by a factor $A$ equals to 65, compared to 40 with the presence of the concrete slab, comparison made for 1 m drop height. Thus, it seems that by spreading the impact load, the concrete slab induces a larger dissipative activity of friction between the sand grains.

With a dissipative layer made of 4 layers of socks, the thickness of this component (15 cm) can be compared with a layer of 15 cm thickness of unconfined sand. The amplification factor in this multilayered structure (or sandwich structure) is slightly higher than the one corresponding to the sand layer. For 2 m drop height, the amplification factor is 55 for the multilayered structure, which is equivalent to a 10 cm thickness unconfined sand layer (Fig. 13). Experiments also show that for a multilayered structure, the best configuration is to use a rigid plate or slab combined with geotextile socks.
Figure 13: sand-sandwich (or multilayered) structure comparison

<table>
<thead>
<tr>
<th></th>
<th>Sand 15cm</th>
<th>Sand 10cm</th>
<th>Pozzolana 15cm</th>
<th>Sandwich 15cm</th>
<th>Sandwich 10cm</th>
<th>Sandwich without slab</th>
<th>Sandwich without geotextile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplification</td>
<td>25</td>
<td>28</td>
<td>31</td>
<td>40</td>
<td>50</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>for h=1m</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Table 4: experimental investigation: amplification factor $A$ for a 1 m drop height

CONCLUSIONS

The aim of this small scale experimental investigation is to give some indications about the energy dissipation capabilities of different structure combinations. It is the transmitted impact force which is the indicator of this dissipation capability: the weaker the recorded impact force, the more the energy is dissipated.

First, the tests were carried out on unconfined granular materials which dissipate energy by elastic and plastic deformations. The experimental results show that the sand and the gravel produce a better dissipative effect than the pozzolana.

Then, multilayered structures show a dissipative efficiency slightly lower than the unconfined sand layer. The best configuration for this kind of structure is to use a rigid slab which when impacted, spread the loading on a sufficient amount of geotextile socks containing sand. When these socks are loosely arranged, the efficiency increases.

Recall that these studies are used to help in the design of a vertical protective structure, the sand layer must be contained in geotextile containers. This is why, showing that the dissipative efficiency of a multilayered structure is comparable to the classical single sand layer used to protect road gallery against rockfall, is a key point to continue our investigation.

However, one must be careful about these experimental results because the impact energy ranges about 400 J. Thus, investigations for higher energies are necessary because our energy
interest range is about several hundreds of kilojoules. For that, we expect to get experimental results at real scale soon.

Afterwards, 3D numerical simulations will be carried out with the Discrete Element Method to complete this study. This method is chosen because of its great suitability to problems involving large deformations resulting from dynamic loads [Magnier, 1988], especially during impact events.

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