Impact load transmission within a half scale sandwich rockfall protection wall

A. Heymann, P. Gotteland, Stéphane Lambert

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Adeline Heymann[1,2,3], Philippe Gotteland[2], Stéphane Lambert[1]

[1] Cemagref, UR ETGR, Domaine Universitaire BP 76, 38402 St-Martin d'Hères, France
adeline.heymann@cemagref.fr ; franck.bourrier@cemagref.fr ;
stephane.lambert@cemagref.fr;

[2] 3SR, UMR5521, DU Grenoble Universités, 38041 cedex 9, Grenoble, France
philippe.gotteland@ujf-grenoble.fr

[3] RAZEL, 3 rue René Razel, 91400 Saclay, France

Abstract. This contribution presents experiments on cellular sandwich rockfall protection structure. Such structures constitute innovative developments aiming at using the cellular technology, classical in the field of civil engineering, for rockfall protection. In order to explore the mechanical behavior of these systems under dynamic loadings, impact experiments are performed and a numerical model of the structure is developed. The experiments consist of the impact by a 260 kg spherical projectile on a structure composed of gabion cages filled with coarse materials in the front part and fine materials in the kernel part. This structure stands against a rigid concrete wall. In a first time, the methods and results are presented focusing on the transmission of the load (stress) in the impact direction.

Keywords: rockfall, protection, dynamic loading

1 Introduction

Reinforced soil structures are used as passive countermeasures against medium to high energy falling boulders. Despite several experimental and numerical studies have been carried out (Yoshida, 1999; Hearn et al., 1995; Peila et al., 2007; Aminata et al., 2008), the design of these dams generally rests on an empirical approach. A thorough analysis of the mechanical response of these structures remains to be done in order to improve their efficiency.

Reinvestigating the principle of a sandwich structure, as first proposed by Yoshida (Yoshida, 1999), an intensive study was initiated to develop cellular structures (the REMPARe project). In this processes, the behaviour of cells under impact has been first studied (Lambert et al., 2009), before investigating the response of a half-scale structure, focusing on the load transmission in the direction of the impact.

2 Materials and methods

2.1 Tested structure

The structure consisted in a two-layers sandwich structure leaned on a rigid reinforced concrete wall (Figure 1).

The first layer, or front part, consisted of 9 gabion cells filled with a coarse material. These geocells were cubic in shape, 500 mm in height. The envelope was made up of a hexagonal or double-twisted wire mesh. The mesh height and width were 80 mm and 100 mm respectively, and the wire had a 2.7 mm diameter. The filling material was a crushed quarry limestone, 80 to 150 mm in grain size coming from the site of Bar-sur-Loup (Alpes Maritimes, France).

The second layer of the sandwich structure, in the kernel part, consisted of a Seine sand cushion. This sand is a well-graded sand which size distribution ranges from 0.2 to 5 mm.

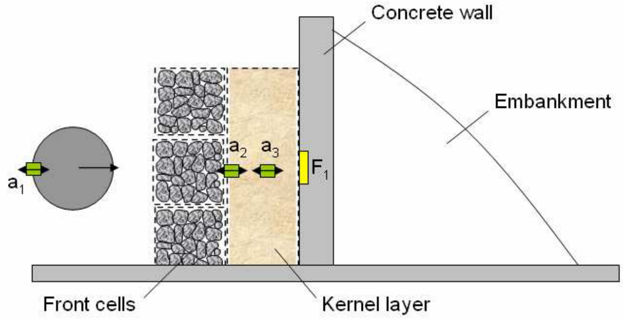

Figure.1. sandwich structure used in the experiment and measurement devices (a_1 : accelerometer on the projectile, a_2 : accelerometer at the interface between the front and the kernel layers, a_3 : accelerometer in the middle of the kernel layer, F_1: stress sensor on the back part wall).

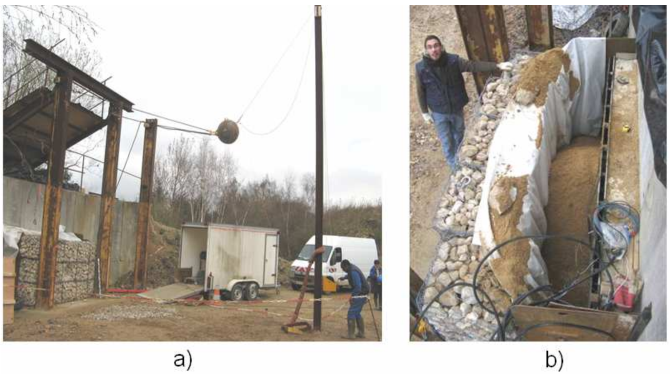

Figure.2. Overview of the experimental device (a) and the impacted structure during the implementation (b).

For an easier implementation, the material of the kernel is not contained in cells, but dumped in bulk. In order to contain this fine material a non-woven-needle-punched geotextile was used (Figure 2b).
On each side, the structure is enclosed by other cells to provide a lateral containment.

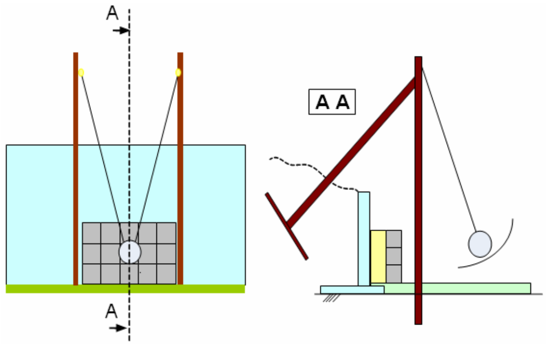

Figure.3. Principle of the experimental device.

2.2. Experimental methodology
These experiments were performed in the CER (Center of Road Study) of Rouen (France). The experimental device (Figure 2a, Figure 3) consists of concrete wall, 3m in height, leaned on a ground consolidated embankment. This set constitutes the back part support. The dropping device is made of two metallic pylons 7 m in height, linked with a transversal girder where two chain slings are tightened. The lifting is completed by a hand cable winch to reach a maximal height of 4.75 m. The tested structure is subjected to a pendular impact by a 260 kg spherical projectile, 54 cm in diameter, and made of a steel shell filled with concrete (Lambert et al., 2009). The maximal energy developed by the projectile is 10kJ. At the beginning of the impact, the trajectory of the projectile is perpendicular to the front face of the structure.
Two types of measures are carried out: acceleration measured on various locations, and measures of the stress transmitted at the support (a_1, a_2, a_3 and F_1 on Figure 1). A triaxial piezoresistive accelerometer is placed on the projectile (a_1). It allowed determining the time evolution of the impact force F_{imp} applied by the projectile on the structure. The duration of the impact, d_{imp}, is deduced from the projectile's acceleration measurements. Accelerometers are also placed at the interface between the front and the kernel layers (a_2) and in the middle of the kernel layer (a_3). All sensors are placed along the impact direction of the projectile before impact, and at the same height as the impact point. These accelerometers are used to measure the time elapsed between the beginning of the impact and the beginning of the displacement at the point considered as well as estimating the amplitude of the compression wave. A stress sensor is placed on the concrete wall (F_1). It provides the time evolution of the stress σ_{tran}, normal to the impact direction on the back part of the structure.
The sample rate was 40 000 Hz. In order to minimize the noise due to high frequency phenomena, signals were submitted to a low-pass Butterworth filter with a cut frequency of 1000 Hz. Then the norm of the acceleration of the projectile was calculated using the three components. The filtering induces a temporal gap between the real and filtered

signal, so the measure of the stress was also filtered with the same cut frequency to keep the same time scale.
The evaluation of the response of the structure is mainly based on the force applied by the projectile on the structure F_{imp} and the stress transmitted by the structure to the support σ_{tran}.
Four successive impacts increasing the impact energy were carried out (2, 4, 8 and 10kJ). The highest energy impact was repeated twice.

3 Results

3.1. Time evolution of the impact force and of the transmitted stress

As shown in Figure 4 (left), the impact force increases with the impact energy. The duration of the impact is about 50 ms, and seems to be independent of the impact energy. The curves of the impact force present a maximum and then a plateau behaviour. With increasing impact energy, the slope of the section preceding the peak increases and the peak occurs earlier. For a 2kJ impact, the maximum of the impact force is 90 kN, and for the first impact at 10 kJ it is 450kN. Comparison of the two 10kJ-impacts show that despite the maximum force for the second impact is higher (490 kN), the two plateau have approximately the same amplitude.

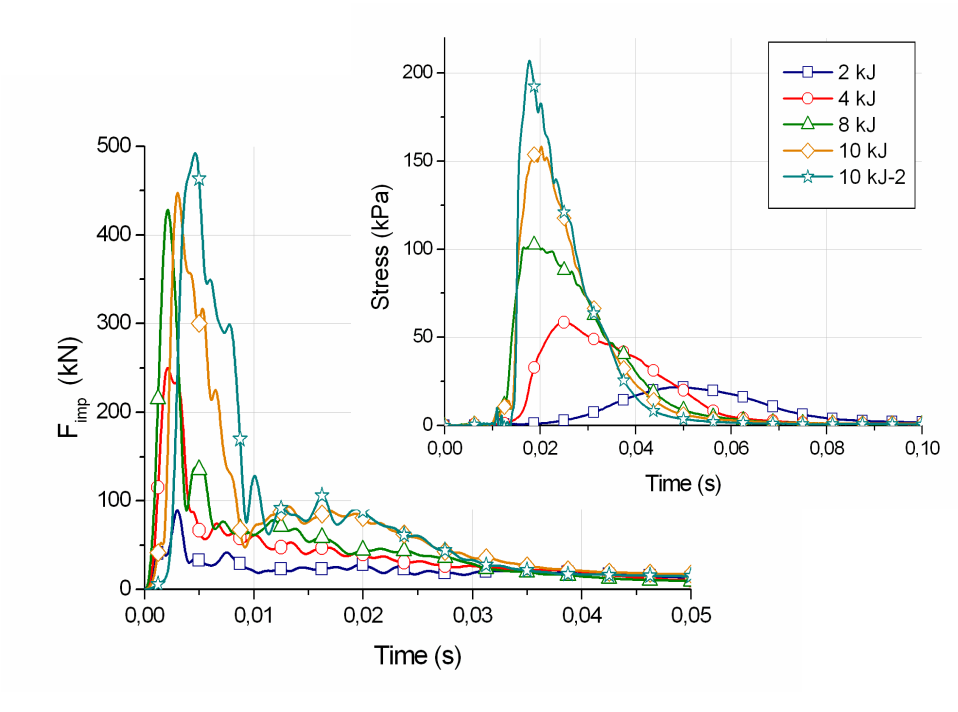

Figure.4. (left) Impact force F_{imp} of the projectile vs. Time for each impact energy; (right) Stress measured at the support vs. Time for each impact energy.

The response of the structure in terms of transmitted stress is pictured in Figure 4 (right). The stress measured at the support increases with the impact energy. For the 2kJ-impact the transmitted force remains little. For other impact energies, a peak occurs approximately 20ms after the impact.

As presented in Figure 5, the maximum transmitted stress increases non-linearly with the maximum impact force. It is assumed to be the consequence of the repeated loadings of the structure, since the answer is higher when the material is compacted.

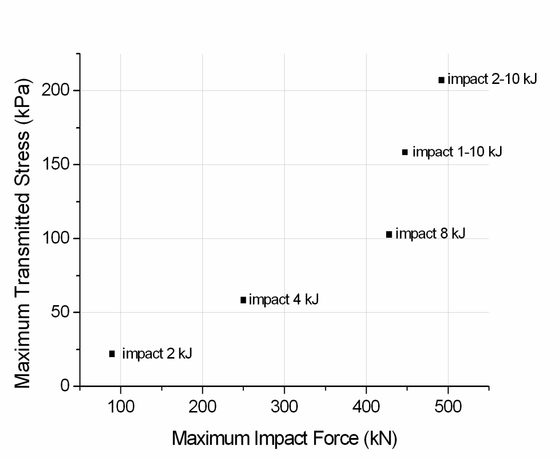

Figure.5. Maximum of stress measured at the support vs maximum impact force for each impact energy

3.2. Compression wave propagation

The Figure 6 compares the data from the different sensors in the case of an 8kJ impact. It takes about 2.5 ms for the compression wave to reach the accelerometer a_2, 5.8 ms for the a_3 accelerometer and 10 ms for the stress sensor. The respective compression wave velocity can then be estimated: 120m/s in the stones cells, and 66m/s in the kernel layer.

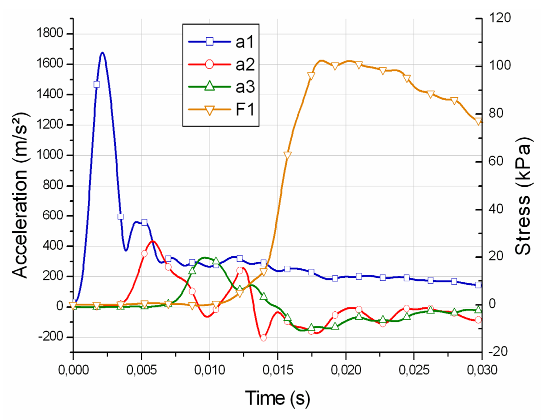

Figure.6. Passage of the compression wave in the structure for an 8kJ impact.

Figure 6 allows also appreciating the variation of amplitude of this compression wave. For an impact at 1700 $m.s^{-1}$, the maximum acceleration measured at the interface between the front and the kernel layers is only 430 $m.s^{-1}$ and the acceleration measured in the middle of the kernel 330 $m.s^{-1}$.

5 Conclusion and perspectives

In order to understand the mechanical response of a cellular sandwich structure under a dynamic loading, a series of impact tests was performed. The response of the structure was evaluated thanks to the impact force and the stress transmitted to its back part support. Results show that the impact force and transmitted stress increase with the impact energy. They also show that the maximum of the transmitted force evolves non-linearly with the maximum of the impact force. This is due the compaction of the material by the successive impacts. The measurement device allows appreciating the evolution of the compression wave in terms of velocity and amplitude.

A numerical model of this structure was developed using a discrete element method. The structure is modelled as an assembly of rectangular cells of the same size representing the gabion cages used in the experiments. The peculiar feature of this model is that the constitutive model used for the different cells depends on the proximity to the impact point. Even if the improvement of this constitutive model is in progress by means of experimental studies on the energy transfer inside a sand layer during rock impacts the model provides a correct prediction of the impact force on the projectile(Bourrier et al., 2010).

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