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# **Kinematic response of an impacted rockfall protection embankment**

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Real-scale impact experiments have been conducted on a rockfall protection embankment, over the 200-2200 kJ kinetic energy range. The structure was made of a two-layer sandwich wall leaned against an earth-fill dam. Gabion cages either filled with stones or a sand-scraped tire mixture constituted the sandwich wall. Different measuring devices were used to monitor the structure response: accelerometers, displacement sensors, high speed camera and geophysical survey. The structure and measuring devices are first described. The results presentation focuses on measurements within the structure for a low energy impact. Results concerning higher projectile kinetic energies are provided. The discussion highlights the main features of the embankment kinematic response based on displacements within the wall in particular.

Keywords: Real-scale experiments, impact, gabion, sand-tire mixture

## **1 Introduction**

Some studies have been conducted with the aim of investigating the mechanical response of rockfall protection embankments based on real-scale experiments, with impact energies ranging from a few hundred to about 5000 kJ (Peila et al. 2011; Lambert and Bourrier 2013). As the tested structures differ in their shape, construction materials and dimension, extrapolation to other structures is not straightforward. Besides, previous experimental studies provide only a few data concerning their impact response and almost no data concerning their response with time.

This paper investigates the kinematic response of cellular sandwich protection structures, first proposed by Yoshida (199), and based on real-time measurements made during successive impact tests.

## 2 Real-scale structure, testing conditions and collected data

The structure consisted of a two-layer cellular sandwich wall leaned against an earth-fill dam (fig. 1). The sandwich wall was 4m in height, 8m in length and 2 m. in thickness (i.e. in the impact direction). It was made from gabion cages either filled with crushed limestone or a mixture of sand and scrapped tires, for mountain-side facing gabions and inner gabions respectively. The aim of such a sandwich wall was to reduce the stress to the earth-fill dam, while allowing an easy repair. The structure impact response was investigated based on both real-time measurements and post-impact measurements. The measurements mainly aimed at evaluating the acceleration and deformation of the structure, in different points, for a given impact loading. In particular, accelerometers were placed at the interface between the front layer and the kernel layer of the sandwich wall and at the interface between the kernel layer and the dam. Displacements derived from acceleration measurements were compared with data obtained from displacement sensors for validation purpose. Modifications to the dam mechanical characteristics were evaluated thanks to tomography. Finally, high speed camera images allowed obtaining data related to the projectile penetration.

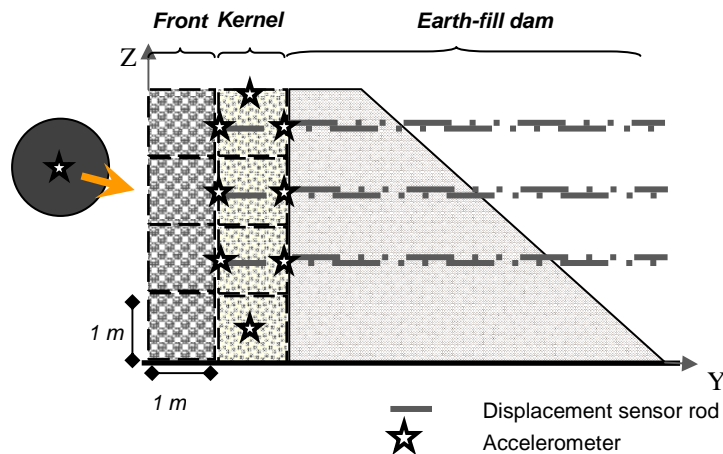


Fig. 1. Cross section of the embankment showing the sensors location in the impact plane.

The impact tests were conducted conveying along an inclined cableway a gravity-driven 6500kg in mass spherical projectile (1.6m in diameter) allowing impacting the structure facing in its center with a 18-24° inclination. The structure was successively impacted at 200, 1000, 500 and 2200 kJ (max. projectile velocity was 26 m/s). The structure was repaired after tests 2 and 3 (1000 and 500 kJ impacts). In the first case, damage was moderate and repair consisted in placing a wire mesh

patch on the facing and backfilling it with stones. In the second case damage was more important and repair consisted in replacing the impacted gabions with identical ones.

## 3 Results

### *3.1 Low energy impact response*

Acceleration measurements allowed deriving the velocities within the wall. For instance, Figure 2 reveals the difference in kinematics between the two points on both sides of the kernel in the case of the 200-kJ impact. It clearly shows the propagation of the displacement wave and its progressive attenuation with the distance to the impact point. The time lag is of about 20ms and the peak velocity reduced by about 60 % between the two points. Five different phases can be distinguished: (I) compression phase of the kernel without any movement at the kernel-dam interface, (II) global displacement of the kernel combined to compression, (III) progressive deceleration of the kernel combined to kernel expansion (IV) the two points move in opposite directions and (V) global kernel displacement in the direction opposite to the impact direction.

The maximum kernel compression was 120mm, reached at  $t=100\text{ms}$ , before decreasing to 25mm at the end of the impact. The succession of high amplitude compression (12% of the kernel thickness) and expansion is attributed to the peculiar mechanical characteristics of the fill material compared to more classically employed materials in geotechnics: its modulus is rather low and its elasticity is rather high (Lambert et al. 2009).

Besides, significant differences in displacement are observed at the kernel-dam interface depending on the distance to the ground (Fig. 3). At the impact height, i.e. 2.5 m from the ground, the displacement mainly occurs along the y-axis, with maximal and residual values of 105 and 50 mm respectively. Closed to the crest (3.5m from the ground), the displacement occurs in both y-axis and z-axis directions, with a similar maximal amplitude 40mm approximately. There is thus a difference in amplitude and orientation.

The crest seems to oscillate, with a negative y-axis displacement value from 300ms, while at the impact height the interface is immobile at 400ms, after an elastic recovery phase.

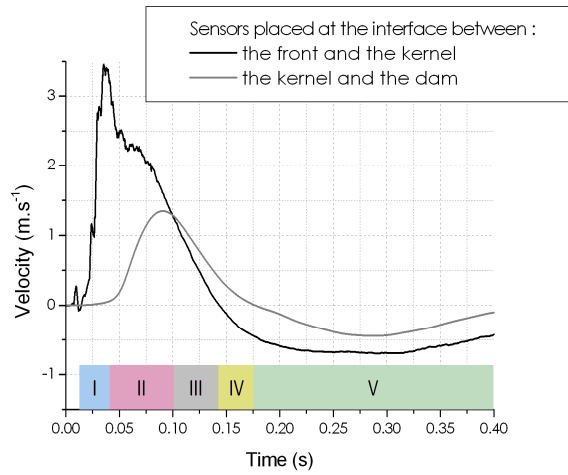


Fig. 2. Velocities within the sandwich wall in the impact direction.

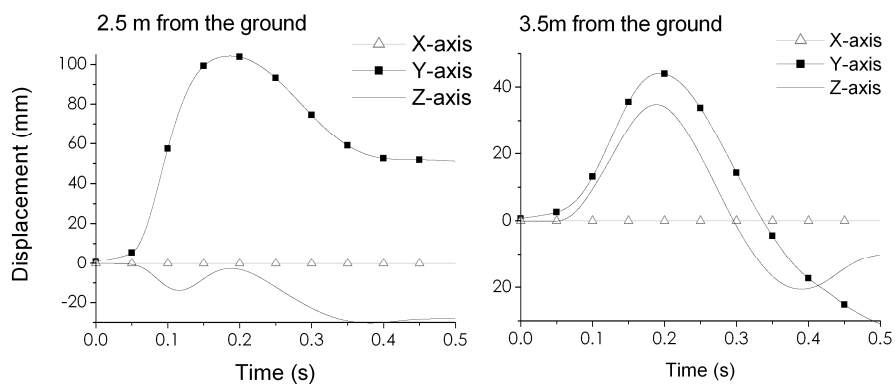


Fig. 3. Displacement of the kernel-dam interface during the first test (200 kJ), at two different heights from the ground.

### 3.2 High energy impact response

A detailed response analysis of the structure response for higher impact energies is not possible because the second impact damaged some sensors and their cables. Nevertheless, the evolution of the wall response to impact can be addressed based on the horizontal displacement measured at the kernel-dam interface in the impact direction. Indeed, the higher this displacement, the higher the stress to the dam.

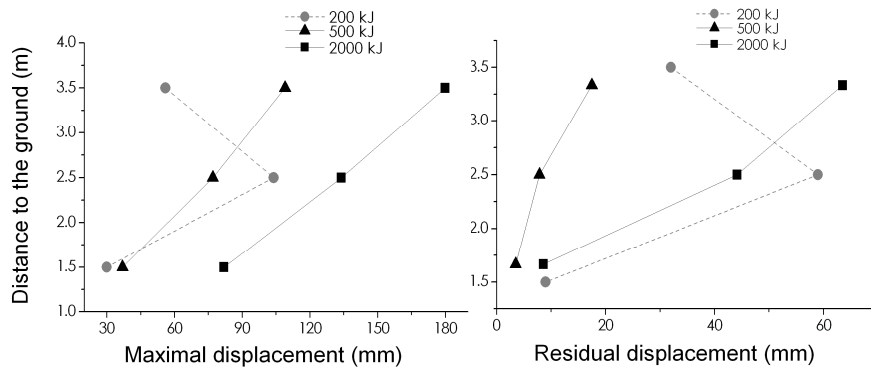


Fig. 4. Maximal and residual values of the displacement of the kernel-dam interface along the horizontal axis during tests 1, 3 and 4.

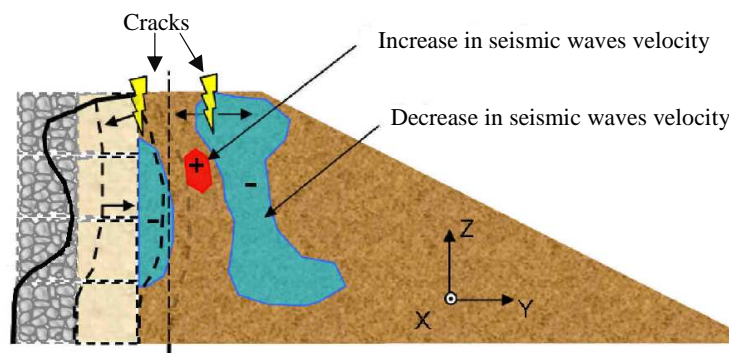


Fig. 5. Schematic representation of the changes observed after the fourth test

Figure 4 globally reveals a change in the structure response from one test to the other: while the first impact evidences strain concentration, the two other impacts reveal a whole structure tilting movement, with higher amplitude closed to the crest. This figure also shows that residual displacements may not be appropriate for evaluating the maximal displacements.

Finally, the interface displacements, i.e. the displacement along the y-axis, are much smaller than the projectile penetration. Indeed the maximal penetrations were 500, 670 and 1010 mm for tests 1, 3 and 4 respectively and residual displacements at the kernel-dam interface were typically 10% the projectile residual penetration.

The difference in displacement, from the impact point to the kernel-dam interface suggests that the vast majority of the sandwich wall thickness reduction is concen-

trated in the front layer, where crushed stones in quantities proportional to the impact energy were observed. By contrast, the kernel layer thickness reduction is much less, due to the elasticity of the sand-tire mixture. This is confirmed in Figure 5 depicting the deformations observed after the fourth tests. Cracks resulted from a reverse movement, after the loading phase. This figure also provides information derived from the geophysical survey conducted after the fourth test, showing both compaction and bulking (increase/decrease of seismic waves velocity resp.). By contrast, the three first tests tended to compact the dam soil, in the impact direction mainly. These trends result from the dynamic nature of the loading.

#### 4 Conclusion

In order to assess the response to rockfall impacts of cellular two-layer sandwich protection embankments, real-scale impact experiments were conducted with projectile translational kinetic energies up to 2200kJ. The structure was instrumented with accelerometers and displacements sensors, in particular.

The response of the structure with time appears to be very complex, with a strong dependence on the impact energy. The contribution of the different gabion fill materials in reducing the stress to the back part has also been shown, demonstrating the interest of such sandwich walls for being part of rockfall protection structures.

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