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Experimental and numerical investigation of the response of geocell-reinforced walls to horizontal localized impact

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A B S T R A C T

The aim of this work is to study the effect of a localized impact on a wall made of soil reinforced with geocells. First, two structures were tested with an impacting remote-controlled car. Such experiments, carried out on 1/10th-scale model structures for practical reasons, are designed to mimic the mechanical response of an alveolar geocell reinforcement system. Two types of constitutive materials were considered for the geocells with very different mechanical properties. The test structures were dismantled after the tests to analyse the influence of the impact on the cell layers, especially within their bulk. Examining the video of the tests captured with two high-speed cameras also helped understanding the phenomena that occurred during impact. These experiments were completed by numerical simulations whose objective was to understand more clearly the causes of the phenomena observed either within the dismantled structures or in the videos.

1. Introduction

The mechanical behaviour of soils reinforced with various types of inclusions such as geosynthetic sheets, steel armatures, geogrids, gabion cells and geocells have attracted attention from many researchers in the recent past (Chen et al., 2013; Moghaddas Tafreshi and Dawson, 2012; Parsons et al., 2009; Saran, 2010; Yang et al., 2012). In particular, the effect of dynamic loads on such structures is a major issue as far as hazard mitigation is concerned. Indeed loadings such as impacts, earthquakes, or blasts, involve complex phenomena that are not clearly understood.

For seismic loading, several experimental and numerical studies are available in the literature (Huang et al., 2011; Koseki, 2012; Lee et al., 2010; Leshchinsky et al., 2009; Ling et al., 2009). In addition, standards such as Eurocode 8-5 (Eurocode 8, 2005) take into account the seismic loadings, considering them as additional equivalent static loads, as proposed by the pseudo-static Mononobe–Okabe method (Okabe, 1924; Mononobe and Matsuo, 1929).

Concerning the effect of blasts on reinforced soils, the papers which have been published so far mainly deal with numerical studies. Experimental studies are scarce (Chew et al., 2003). This is due to the fact that such experiments are generally risky and need highly specific resources. In addition, they are often performed within the framework of private or military investigations and therefore generally remain unpublished.

The case of impact loadings is more and more attractive in the literature though only the case of rockfall embankments has been addressed in practice until now (Nomura et al., 2002; Bertrand et al., 2005; Lambert et al., 2009; Bourrier et al., 2010, 2011). Furthermore, standards do not really take into account this type of loading because only the deforming capacities of the impacting structure (e.g., a vehicle) are considered in the case of shock rather than those of the impacted structure (Eurocode 1, 1991).

In this context, the aim of the present work is to examine the effect of a localized impact on soils reinforced with geocells. Such reinforced structures can potentially be used to protect pre-existing structures against impacts, so this type of study is necessary to investigate their capacity to provide protection.

Model tests were carried out instead of full-scale tests. The obvious reason is that they can be much more easily performed compared to full-scale tests, both in terms of cost and safety. In fact, full-scale tests can be considered as a final step of a sustainability study for a given solution. This objective is however out of the scope of the current study. Model tests constitute an essential preliminary

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stage for observing and understanding qualitatively the mechanisms involved, even in cases where the similarity laws are not satisfied. In the current study, it is too complex to fulfill similitude laws to provide a reliable relationship between model and full-scale responses. In this context, the aim of this study is to investigate the mechanisms involved and to reproduce them using Discrete Element Method (DEM) while assuming that similar behaviours are expected at normal scale. Two impact experiments were first carried out on geocell structures at a scale of 1/10th. Two materials featuring very different mechanical properties were chosen for alveolar reinforcement: paper and polymer. These experiments were captured by two high-speed cameras at the same time for thorough investigation of the phenomena occurring during the impacts. The models of reinforced structures were then dismantled and the deformation of the different layers was studied. Finally, numerical simulations were carried out to analyse the global and local mechanisms occurring in the reinforced structures. The results obtained from these experiments and the calculations used are presented and discussed in the different sections of the paper.

2. Experimental study

2.1. Materials and methods

2.1.1. Details of the test structures

Two reinforced material structures were tested in this study. The difference between these two structures is due to the nature of the reinforcement. Each structure was composed of 19 layers of geocells filled with a specific material. In the horizontal plane, each layer was 120 cm in length, 55 cm in width and 2.5 cm in height (Fig. 1). The 3 layers at the bottom of the wall were placed below the ground surface. The total height of this laminated structure was about 47 cm, including the anchoring layers. The whole structure was built up inside a U-shaped wood coffering, which constituted the boundary conditions of the model on three of its sides. This approach is similar to that used by Racana et al. (2003) wherein they have studied the response of similar structures under static loading. The current size of the cells is expected to mimic the response of an M3S® system to the scale of 1/10th. Apart from the cells located in front of the structures which deformed during the filling and compaction stages, the shape of the cells located in the bulk was nearly square, even after compaction.

The intercellular bonds were formed by 2 staples placed along the width of the reinforcement strips. After filling, the length of the inner cells along the diagonal was about 5.5 cm. They were square in shape whereas the cells located along the boundary were curved. The boundary conditions were made rigid. Before filling the cells, each layer was pre-extended with a wooden strap structure. After filling, the material was compacted twice: before and after the wooden straps were removed. This process was repeated successively for each additional layer placed on those built beforehand, thus giving rise to the desired model structure.

2.1.2. Mechanical properties of the alveolar reinforcement

Two different reinforcements were studied, namely polymer and paper, which were intended to provide very different mechanical responses. The first was an extruded polyethylene film (PE) with a thickness of 0.1 mm. The second was greaseproof paper (GP).

Tensile tests were performed on both materials in order to characterize and underline their very different mechanical responses. The initial stiffness and strength were also determined because these quantities are used in the second part of this study dealing with the mechanical model. Two types of specimens were considered for each material: a single strip and two bonded strips.

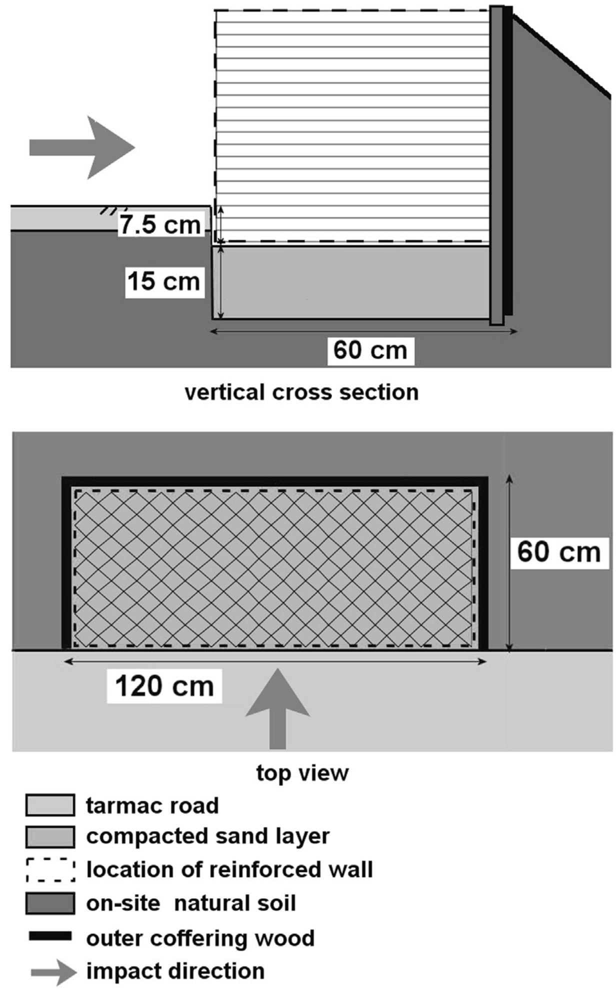

Fig. 1. Diagram of the experimental reinforced wall.

The size of the first type of specimen was 25 × 200 mm^2. The second type of specimen was made of two strips bonded at mid-length. The strips were embedded in compression clamping devices. Tensile tests were conducted with a cross-head speed of 4 mm min^{-1}. A force transducer and an extensometer were employed to measure the applied tensile force and the global longitudinal elongation of the specimen, respectively. The mean strain and the tensile strength were then deduced from the force/elongation curves.

The responses of the different specimens to the tensile tests are shown in Fig. 2. For the single strip specimens, it can be observed that the GP specimens exhibit a quasi-linear elastic response with an initial stiffness of 250 kN/m. The PE specimens have response presenting a linear phase with a stiffness of 16 kN/m followed by a yielding phase. Both bonded strip specimens exhibit a plastic response and a force at failure equal to 0.5 kN/mm and 0.25 kN/mm, respectively. Observing the specimens after failure revealed that the strips tore gradually for GP whereas they deformed and plasticized for PE.

2.1.3. Fill material

2.1.3.1. Definition of the fill material. The fill material used was a mixture made of equal volumes of expanded clay and polystyrene micro-beads. The expanded clay particles presented a sub-spherical shape with diameters ranging from 0.5 to 2.5 mm. The diameter of the polystyrene micro-beads ranged from 0.9 to 1.5 mm. These