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Experimental study of the mechanical behaviour of soil reinforced by geocells

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ABSTRACT: This paper focuses on the experimental study of a wall reinforced with geocells with a special emphasis on the interaction between the cells. Two reinforced reduced-scale walls have been built up with several geocell layers without connections. The first wall is reinforced by paper. Its failure is regular and it has been observed that the friction angle of the reinforced soil is the same as the soil without reinforcement. The cells give rise to an effective strength which can be interpreted as an apparent cohesion. Some previous tests carried out on reinforced soils with connected geocells gave similar global behaviour. A second wall, reinforced with a softer material, confirmed the failure mechanism observed with the first wall. In addition, some pull-out tests have been performed to simulate the mechanical behaviour of passive corrugated strip anchorage. An abutment phenomenon due to the corrugated shape is clearly pointed out and studied.

1 INTRODUCTION

The study is an experimental analysis, of the mechanical behaviours of a geocell wall. The interaction between the geocells, the influence of the textile stiffness and the behaviour of passive anchorage are studied to optimise the type and the repartition of the inclusions. Through this study, it is expected to better understand the mechanisms in the wall due to the geometry of this reinforcement procedure.

2 STRUCURAL STUDY OF REDUCED-SCALE WALLS

2.1 *Experimental approach*

Many experimental analyse of geocell reinforced walls show that the reinforcement leads to a shear strength increase which can be assimilated to an apparent cohesion (Gourvès et al. 1996, Reiffsteck 1996). The purpose of the present experiments is to study the effect of geocells without connections on the mechanical behaviour of geocell reinforced walls. Two reinforced reduced-scale walls have been built up with several nonconnected geocell layers. The only difference between these reduced-scale walls is the mechanical properties of the constitutive material of the reinforcement. In both cases, the filling sand has a friction angle of 38° and has no cohesion.

2.2 *Paper reinforcement*

The first wall to be tested is reinforced by paper nonconnected geocell layers. The Young's modulus of the paper is 3GPa. The size of each sheet is 1.7x70x83cm. The diameter of the inscribed circle of each cell is roughly 5cm. 41 layers are used for this experiments to obtain a wall of 70cm of height.

The loading is applied to the wall through a metal load repartition plate. The area of this loading plate is 0.2m². A 100kN jack and its hydraulic power station are used. The jack is not attached to the load plate and permit the rotation of the plate.

The measurements of the external behaviour are based on the analysis of the facing strain and the sheet displacement. The measurement controls nine displacement sensors (from A to I) and one force sensor (sensor J) (see Fig 1).

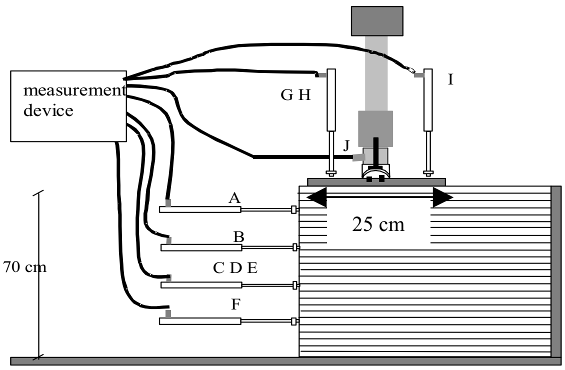

Figure 1. Equipement of the wall.

Friction occurs between the soil and the lateral plates. To avoid this effect, the lateral plates are lubricated (the soil is protected by a thin plastic membrane and grease). Sensors D and E permit to study the lateral effects. Sensors A, B, C ,F permit to analyze the facing displacement on the middle of the wall. The loading increases at a fairly linear rate, as can be observed in Figure 2 and Figure3. No boundary effect is obtained (see Fig. 2).

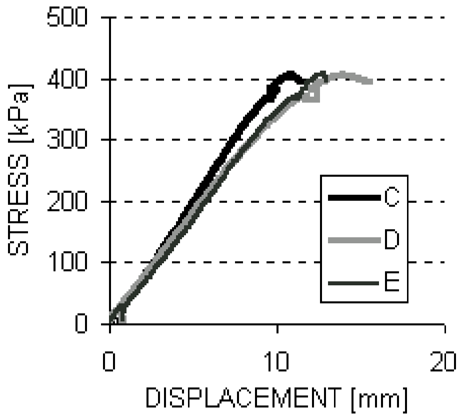

Figure 2. Displacement measurement. Boundary effect

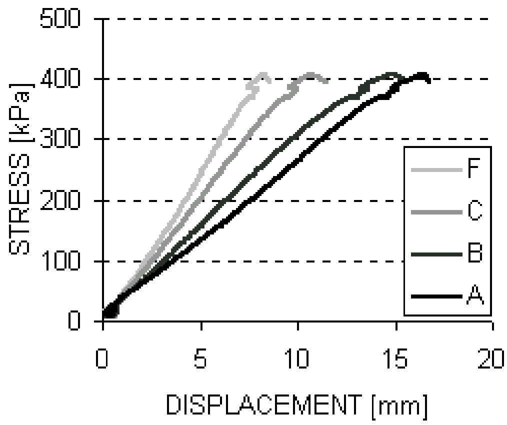

Figure 3. Displacement measurement. Facing displacement

The load-displacement relation provides the global stiffness of the wall defined by the ratio between loading and displacement of the loading distribution plate: 7kN/mm.

At a load of 80kN, a sudden collapse of the wall occurred. The failure line of Mohr-Coulomb type underlines that the soil-geocells composite exhibits the same friction angle as the filling sand. The cells have an effective strength which can be interpreted as an apparent cohesion c_a=100kPa (see Fig. 4).

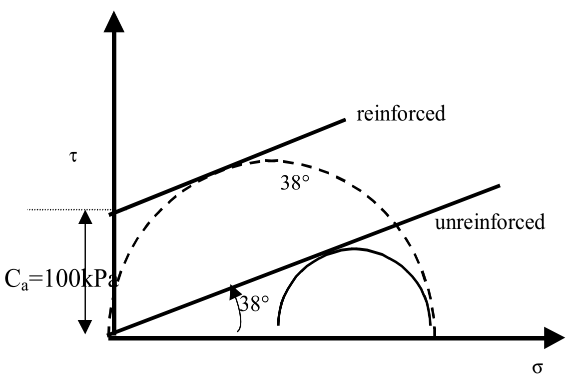

Figure 4. Shear strength increase

The increase of resistance, which is comparable as an apparent cohesion, is due to the density and the strength of the reinforcement.

With the limit equilibrium method of the Mohr-Coulomb corner, the tension sum of the reinforcement can be determined as :

$$T = (F + W)\frac{\cos(\pi/4 - \varphi/2) - \tan(\varphi).\cos(\pi/4 + \varphi/2)}{\sin(\pi/4 - \varphi/2) + \tan(\varphi).\sin(\pi/4 + \varphi/2)}$$

where W is the weight of the Coulomb corner, F the vertical loading and φ the friction angle of the filling soil.

The block method gives the average tension in each reinforcement. A comparison between the average tension and the strength can be performed with the tensile test. The reinforcement of the wall brokes under traction forces and not under shearing ones. It is important to notice that the passive anchorage was not deformed.

2.3 *Polymer reinforcement*

The Young's modulus of the polyan used in the second experiment is thirty times less important than the modulus of the paper.

Therefore in this second experiment the usual displacement sensors could not be used to measure the D-3 facing displacement. The dimensions and the design of the wall are the same as the paper reinforced one. Only the distribution plate is equipped with displacement and force sensors.

The facing displacement is captured by a video system (Peuchot 2000). Following to the observation of the gravity center of some marks, a three-dimensional measurements of displacement is obtained with a suitable programme. The distribution plate is also determined by the cameras. The accuracy of this technique is 1/10000 of the distance between the instrumented object and the video camera. In this experiment, the displacements are measured with an accuracy of 0.1mm (the camera is at 1 m from the wall).

The measurements of the facing obtained with the forty-two marks show that the global displacement of the facing is homogeneous (see Fig.5).

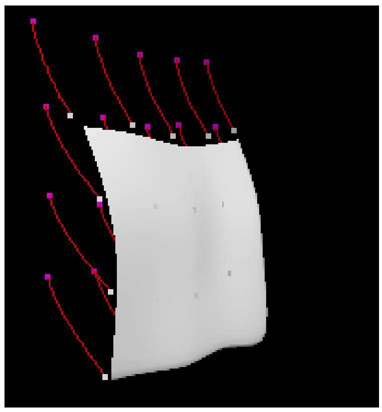

Figure 5. Displacement evolution

The shearing zone is observed for each layer (see Fig.6). The passive anchorage has not been subjected to any strain.

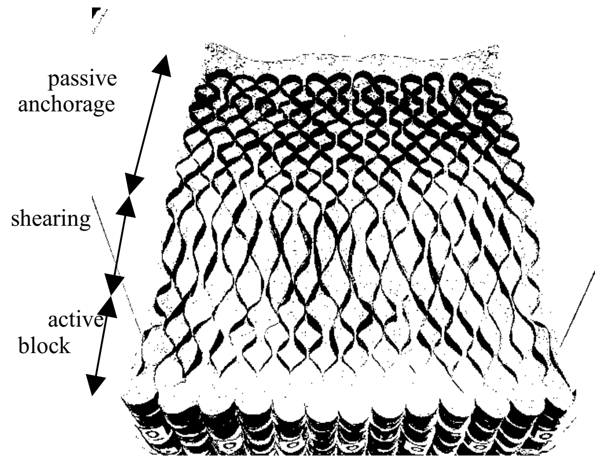

Figure 6. Layer's distortion

The failure surface and the residual distortion of the reinforced soil are eventually presented in Figure 7.

The shearing zone is bounded by the passive anchorage and the active block. The failure of Mohr-Coulomb type shows that the composite reinforced soil exhibits the same friction angle as the filling soil

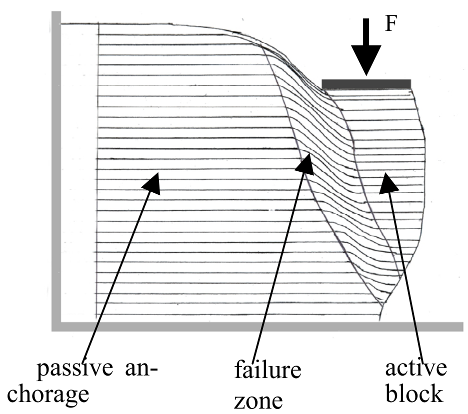

Figure 7. The failure surface

2.4 *Comparison between the two reinforced walls*

The only difference between the paper and the polyan reduced-scale walls is the nature of the reinforcing material. The behaviour of a reinforced soil depends on the mechanical characteristics of the reinforcement. The global stiffness of the soil-reinforcement composite is 7kN/mm in the first case and 1.4kN/mm in the second case. The magnitude of the displacement is very sensitive to the Young's modulus of the geotextile.

Nevertheless, the failure mechanism is the same: no passive anchorage displacement is detected. An active block corner clearly appears.

The mechanical behaviour of these reduced-scale walls brings to the fore that the passive anchorage have an essential function. Some pull-out tests were therefore performed to analyse the mechanical response of this anchorage.

3 PULL OUT TEST

3.1 *Introduction*

The first part of the study permits to analyse the global behaviour of a reduced-scale walls reinforced by non-connected geocells. It shows the main function of the anchorage. Pull-out tests are usual to study their mechanical behaviour (Hayashi 1994) (Sobhi 1996) (Raju 1998) (Sawicki 1998). The same method will be used to analyse the behaviour of a non-connected geocell layer when an extraction loading is applied. The following part describes an experiment where only a small part of the layer is submitted to the pull out test.

3.2 *Experimental program*

The mechanical behaviour of a corrugated strip inserted vertically into the soil and submitted to an extraction test is first study. Comparative studies are set up with a linear strip put into the soil vertically and then horizontally. The aim of this comparative study is to point out the increase of strength due to the membrane behaviour of the corrugated anchorage.

3.3 *Experimental device*

The anchorage strip are extracted with a jack feeded by an hydraulic power station (see Fig.8). The vertical loading is applied by an air bag. A measurement device permits to analyse the load-displacement relationship (LVDT sensor (1) and load cell) of an ancorage strip. Another LVDT sensor (2) is used to study the displacement of the end of the strip.

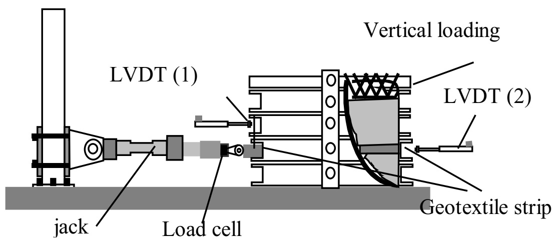

Figure 8. Pullout tests device

3.4 *Comparison*

The pullout tests are realised on three configurations of the geotextile strip and five different vertical loadings. (see Fig. 9)

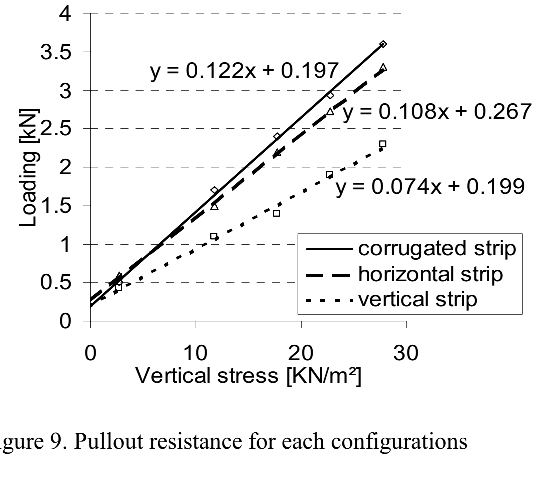

Figure 9. Pullout resistance for each configurations

These curves underline the increase of resistance due to the undulation and the abutment phenomenon.

3.5 *Numerical model of a corrugated strip*

To understand the mechanical response of a corrugated anchorage, a numerical model is studied. The numerical model uses the finite difference method (Billaux 93). This model built with the Flac package allows to study qualitatively the ancorage behaviour. The geotextile strip is modeled with cable elements. This numerical approach permits to analyse the abutment phenomenon created by the undulation at the time of pullout (see Fig. 10).

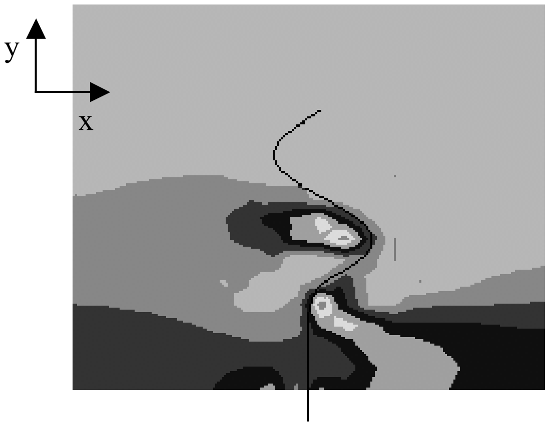

Figure 10. Stress repartition onto direction x

The extraction of a corrugated strip create transverses displacement of the strip and generate an increase of normal stress of the geotextile. This abutment phenomenon generates more resistance during the pullout test.

4 CONCLUSION

The reduced-scale wall experiments show that geocell reinforcements induce an apparent cohesion. Some previous tests carried out on reinforced soils with connected geocells gave similar results in terms of displacement and strength. Consequently, the geocells without connections exhibit the same properties as the geocells with connections in this type of test.

The two reduced-scale walls presently studied underline the influence of the stiffness of the reinforcement. With the rigid reinforcement, a fragile failure is observed. The second wall reinforced by soft material pointed out a plastic response without collapse. Nevertheless, the global failure mechanisms is characterized an active block (Mohr-Coulomb corner) and a passive anchorage separated by a shearing zone in both cases.

Some pull-out tests carried out on several geotextile stripshave show the abutment phenomenon that occurs when corrugated strips are used. After this global analysis we must study different local behaviours. We realised some pullout tests to characterise the anchorage behaviour. These firsts pull out tests, realised one a small part of a geocell layer, brings to the fore an abutment phenomenon due to the corrugated strip.

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