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Mechanical behaviour of soil reinforced by geocells

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ABSTRACT : Some techniques of earth reinforcement are based on geocells. This paper deals with the interaction between the geocells and the mechanical properties induced by the reinforcement. After the stage of soil densification, geocells can be roughly considered as blocks. Since the different cells are overlapped, the function of the mechanical connections between the cells must be clarified. To answer this question, an experimental and numerical analysis has been performed. The mechanical behaviour of the cellular layers will be presented in this paper and illustrated with the main results of the experimental and numerical studies.

1 INTRODUCTION

A reinforced soil is a composite material made of inclusions resisting to the traction forces and placed into a compacted soil. The interaction between the soil and the reinforcement is essential for a good transmission of the stress. This interaction is usually created by the use of granular materials which permits to generate a rubbing interface between the soil and the reinforcement. The concept of soil reinforcement with geocells gives some more complex interactive mechanisms and features confined soil. Among the different techniques of cellular reinforcement, the Sol Solution walls made of three-dimensional geocells is studied. This geocell reinforcement technique has contributed to realize more than thirty walls in France. For example, Sol Solution has developed an innovative technique consisting in tank confinement based on a complete stability study carried out with earthquake resistant data (see Figures 1, 2).

The present new research consists in an analysis of the mechanical behaviours of the geocell wall. The structural behaviours of geocell reinforcement,

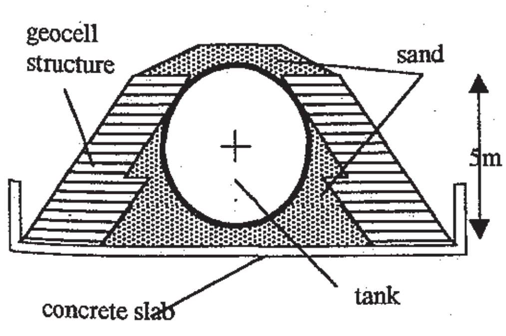


Figure 1. Confining transverse section.

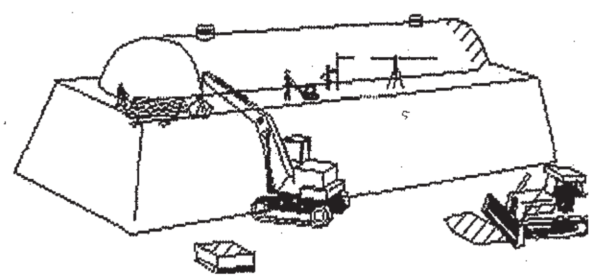


Figure 2. Building site scheme.

the interaction between the geocells and the influence of the textile modulus are studied to optimise the type and the repartition of the inclusions. It is expected to better understand the mechanisms of this process.

2 BEHAVIOUR OF ONE GEOCELL LAYER

2.1 *Experimentation*

This first experiment allows to analyse the interaction between nonconnected geocells. The filling material is a two-dimensional granular medium (Schneebeli 1956, Mezghani 1987). The layer rests onto an inclined plane so that it is mainly subject to the force of gravity (Fig. 3).

This experiment is useful to study the compaction effect of the structural behaviour. When the force of gravity is applied to the geocell layer, the lack of density of the granular medium creates voids inside the geocells. After the stage of densification, geocells can be roughly considered as blocks. The compaction effect is clearly pointed out by the small deformation (less than 1%) of the layer with an important densification.

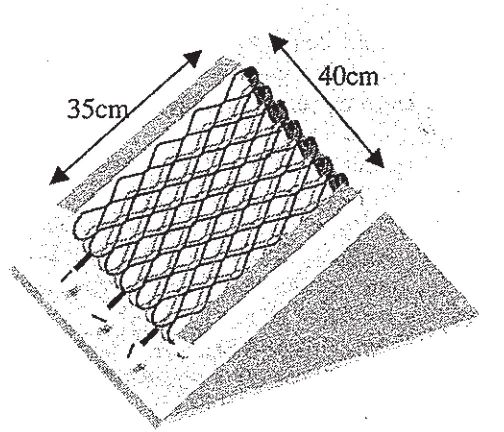


Figure 3. Experimental setup.

2.2 *Numerical approach*

The numerical model uses the finite difference method (Billaux 1992). This model built with the FLAC package allows to study qualitatively of the nonconnected geocells' behaviour. Geocells are modeled with the cable elements (Fig. 4). This numerical approach permits to better understand the interaction between the different cells.

The gravity force is applied to the geocell layer which is fixed at the top by beam elements. The mesh and boundary conditions are shown in Figure 4.

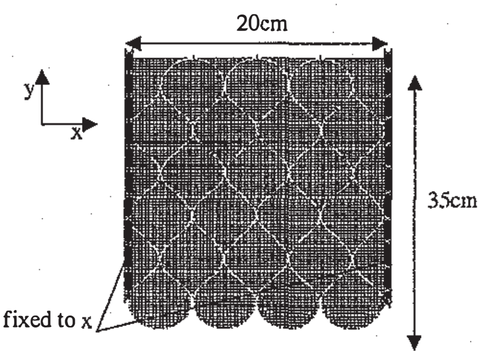


Figure 4. Geometry and boundary conditions.

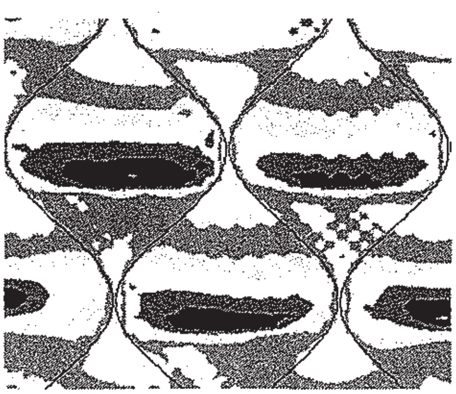


Figure 5. Horizontal stress repartition.

The interaction between the different cells is emphasized by the repartition of horizontal stress. The stress concentration in the middle of each cell is presented in Fig. 5.

This stress repartition shows that the geocells create a rubble mechanism.

2.3 *Conclusion*

Those experimental and numerical approaches allow to analyze the interaction between the geocells. This interaction depends on the density of the filling material as well as on its compaction. With an important density, geocells can be roughly considered as blocks. Their interaction creates a self-blocking balance.

3 STRUCTURAL STUDY OF REDUCED-SCALE WALLS

3.1 *Experimental approach*

Many experimental analysis of geocell reinforced walls show that the reinforcement leads to a shear strength increase which can be assimilated to an apparent cohesion (Breuil 1993, Gourvès 1996, Reiffsteck 1996). The object of these new experiments is to study the effect of geocells without connections. Two reinforced reduced-scale walls have been built up with several nonconnected geocell layers. The only difference between those reduced-scale walls is the mechanical properties of the reinforcement. The filling sand has a friction angle of 38° and has no cohesion.

3.2 *Paper reinforcement*

The wall to be tested is reinforced by paper nonconnected geocell layers. The young's modulus of the paper is 3GPa. The geocell layers dimensions are hight 1.7cm, depth 70cm and length 83cm. The diameter of each cell is roughly 5cm. The loading is applied to the wall through a metal load repartition plate. A 100kN jack and its hydraulic power station are used.

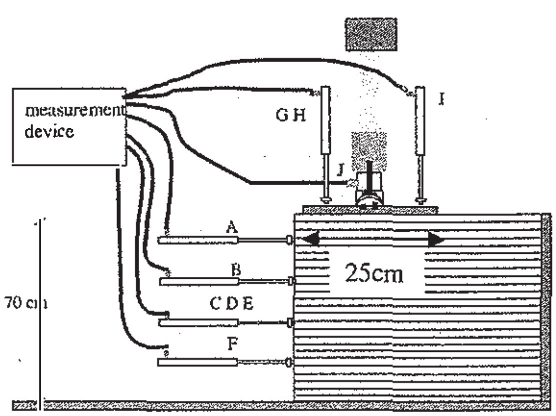


Figure 6. Wall instrumentation.

The measurements of the external behaviour are based on the analysis of the facing strain and the sheet displacement. The measurement device helps us to control nine displacement sensors (from A to I) and one force sensor (sensor J) (Figures 6, 7).

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. The loading increases at a fairly linear rate, as can be observed in Figure 8. No boundary effect is obtained (see Fig. 8-a).

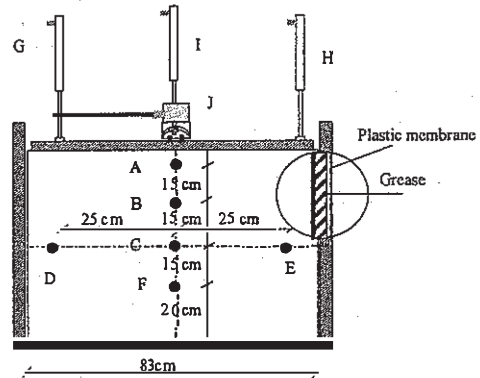
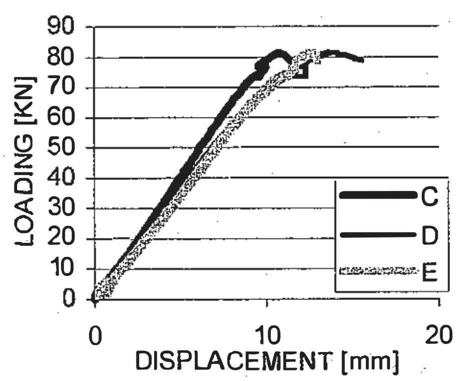
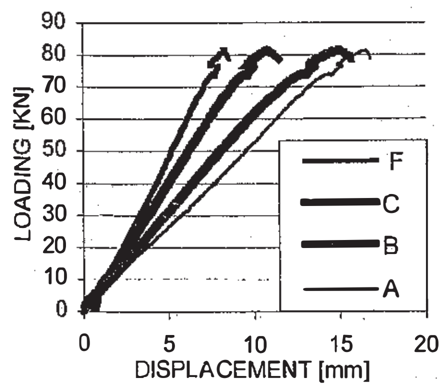


Figure 7. Facing instrumentation.



a - Boundary effect.



b - Facing displacements.

Figure 8. Displacement measurements.

The stress-strain relation applied to the loading distribution plate permits to determine the stiffness defined by the ratio between applied loading and displacement : 7kN/mm.

At a load of 80kN, a sudden collapse of the wall occurred. The failure line (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 (Fig. 9).

With the limit equilibrium method of the Coulomb corner, the tension sum of the reinforcement can be determined.

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

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 broke with the traction forces and did not with the shearing strength. It is important to notice that the passive anchorage has not been deformed.

3.3 *Polyan reinforcement*

The Young's modulus of the polymer used in the second experiment is thirty times less important than the modulus of the paper (Fig. 10).

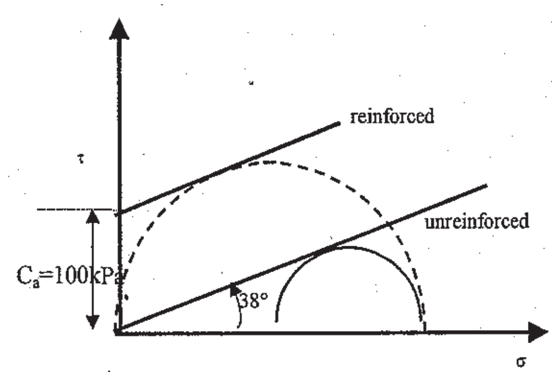


Figure 9. Shear strength increase.

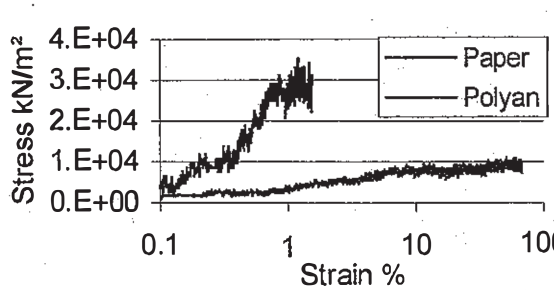


Figure 10. Stress/strain curve : Paper and polyan specimens.

In this second experiment the usual displacement sensors could not be used to measure the facing strain. The dimensions and the design of the wall are the same as the paper reinforcement's one. Only the distribution plate is equipped with displacement and force sensors (Fig.11).

The facing displacement is captured and taped by a video system (Peuchot 2000). Following the observation of the gravity center of some marks (Fig.12) the three-dimensional measurements of displacement is obtained. 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 accuracy is therefore of 0.1mm (the camera is 1 m far from the wall).

The measurements of the facing obtained with the forty-two marks show that the global displacement of the facing is homogeneous (Fig.13).

This second structure is softer than the paper geocell reinforcement. An homogeneous displacement of the plate and an initial stiffness (ratio between applied loading and displacement) of 1.4kN/mm (Fig.14) are observed.

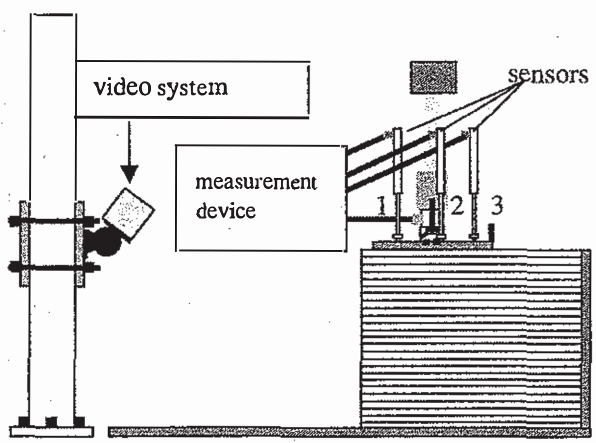


Figure 11. Experimental shape.

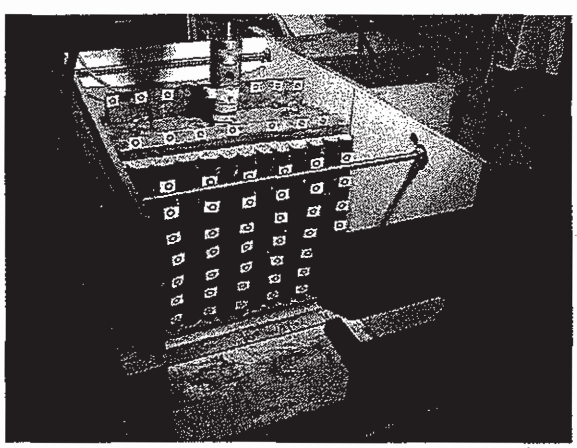


Figure 12. Experimental setup.

The shearing zone is observed for each layer (Fig.15). The passive anchorage has not been subject to any strain.

The failure surface and the distortion of the reinforced soil are presented in Figure 16.

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.

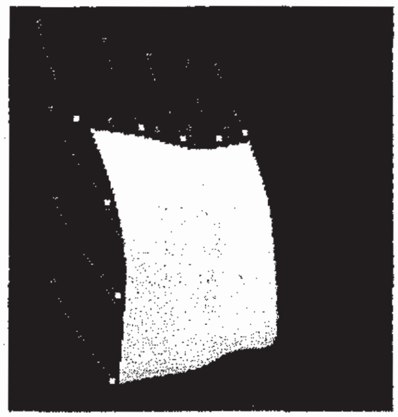


Figure 13. Displacements evolution.

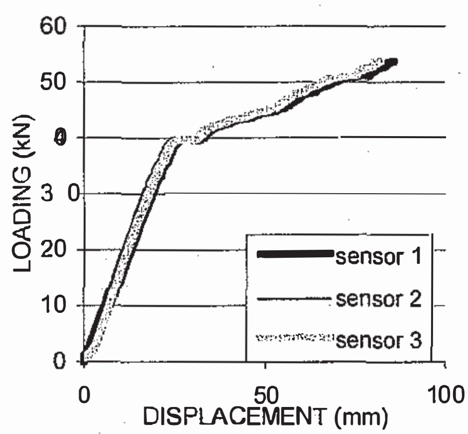


Figure 14. Plate displacement.

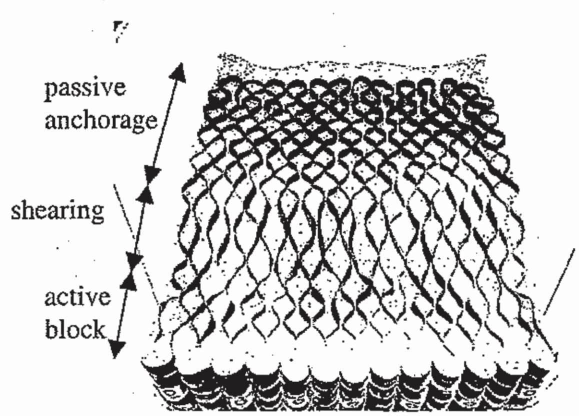


Figure 15. Layer's distortion.

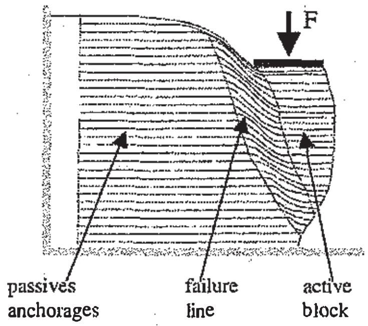


Figure 16. The failure surface.

3.4 *Comparison between the two reinforced walls*

The only difference between the paper and the plastic reduced-scale walls is the nature of the reinforcing material. The ratio between their elastic modulus is about thirty. The behaviour of a reinforced soil depends on the mechanical characteristics of the reinforcement. In this case, the initial stiffness of the composite soil-reinforcement is 7kN/mm for the rigid structure and 1.4kN/mm for the soft wall. 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 movement is detected, the same phenomenon is observed. We have an active block corner.

4 CONCLUSION

The mechanism of a geocell layer under loading is analysed to better understand the behaviour of a geocell reinforced wall. Cells' interactions are analysed with a geocell layer without connections. This approach is useful to observe the rubble mechanism. The reduced-scale wall experiments show that geocell reinforcements can be assimilated as an apparent cohesion. Failure mechanisms are not different if a soft or a rigid structure is used. 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.

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