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Soil/reinforcement interface characterization using three-dimensional physical modeling

A. Abdelouhab, D. Dias & Y. Bourdeau
INSA de Lyon, LGCIE, France

N. Freitag
Terre Armée Internationale/c/o Ménard-Soltraitement, France

ABSTRACT: Several extraction tests on geosynthetic strips and ribbed steel strips, developed by the *Terre Armée Internationale*, were carried out at the LGCIE laboratory of the INSA Lyon. These tests permit to follow the imposed tension as well as the displacements of several points along the strip (geosynthetic and metal) and to highlight their stiffness influence. The analysis of the tension/displacement curves makes it possible to define the interaction law between the soil mass and the reinforcement by an analytical modeling. From the analysis of these results, the influence of the reinforcements extensibility is highlighted.

1 INTRODUCTION

The soil mass reinforcement by horizontal strips constitutes a complex interaction soil/structure problem. For a fine understanding of this interaction, a specific knowledge of the behaviour of the constitutive materials (ground, strips) as well as interface properties between these elements is necessary. The Reinforced Earth method uses strips embedded in layers to grip soil strongly enough to enable the construction of high vertical banking, large embankment or abutments and is included in this category. Safety for short and long-term must be ensured. It requires stability checking and control of the strain level reached during the life cycle of such works.

The reinforcements used in Reinforced Earth structures are most commonly made of ribbed steel strips, however in aggressive environments smoother geosynthetic strips based on high-tenacity polyester are used, which exhibit some relative elongation. The design methods created for the structures reinforced by metallic reinforcements and thus inextensible were brought to be extrapolated to extensible materials. The difference in behaviour of these two types of reinforcement induces the definition of elongation limits beyond which the behaviour of the structure may be different. In order to adapt and to improve these methods, a better knowledge of the interaction between the soil mass and the reinforcement strips seems necessary in order to develop the comprehension of strip-reinforced structures.

Previous studies Schlosser (1981), Segrestin and Bastick (1996) studied the behavior of the geosynthetic straps and established soil/reinforcement interaction laws. However, the studies concerning the dilatancy influence in the grounds, reinforced by extensible reinforcements, are very few Lo (2003). The realization of the tests at various levels of surcharge permits to deduce this influence.

This paper presents the geosynthetic straps behaviour used in the soils reinforcement. It consists of pull out tests of steel and geosynthetic strips in a three-dimensional physical modelling. This type of modeling is carried out in a three-dimensional metal tank. It permits to reproduce the influence of various parameters such as the soil dilatancy which plays an important part in this type of reinforcement. Each of these test have been realized in controlled and instrumented conditions. From this experimental study, the Soil/Reinforcement interface is deduced by analytical methods and permits to improve the current knowledge state.

2 MATERIAL AND METHODS

2.1 *Reinforcements*

The tests were carried out on two types of reinforcement (figure 1), the extensible geosynthetic strips and ribbed steel strips. Extensible inclusions are presented in the form of geosynthetic strips containing

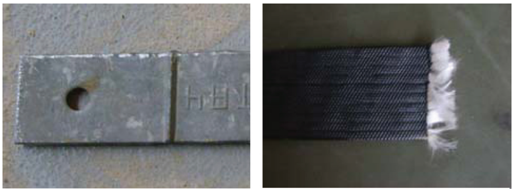

Figure 1. Ribbed steel strip and OMEGA geostrap.

Figure 2. Test tank.

polyester fibers at high tenacity protected by a low density polyethylene sheath. The dimensions of these strips are: 50 mm width and 2 mm thickness. The *Terre Armée Internationale* makes use of these straps for the fully synthetic Omega® system. The advantage of this system lies in the fact that it removes any metal intermediary (thus corrodible) between the concrete facing and the reinforcement strips. The steel strip is made of galvanized and ribbed steel and known under the name of High Adherence strip (HA 50x4). In this case, the dimensions are: 50 mm width and 4 mm thickness.

2.2 *The test tank*

The test tank has large inner dimensions: 1.10 m width, 1.10 m height and 2.0 m length. An air cushion makes it possible to apply an overload. It is placed between the sand and the tank closure. This cushion is inflated under pressure which is controlled by a pressure gauge. Externally, an extraction jack permits to extract the strips and measure the tension load. All the measurements sensors are connected to a computer.

2.3 *The material (sand of Hostun RF)*

The material used in the tests is fine sand known under the name of Hostun RF sand. Various authors were interested in this sand (Gay 2000, Gaudin 2002). Main physical and granulometric characteristics are deferred on table 1.

Table 1. Characteristics of the Hostun RF sand.

Characteristics	Value
Granulometry (mm)	0.16–0.63
D50 (mm)	0.35
Maximum index of vacuums	1.041
Minimal index of vacuums	0.648
Unit weight of the grains (kN/m^3)	26.5
Maximum volumic weight (kN/m^3)	15.99
Minimal volumic weight (kN/m^3)	13.24
Angle of friction	38°

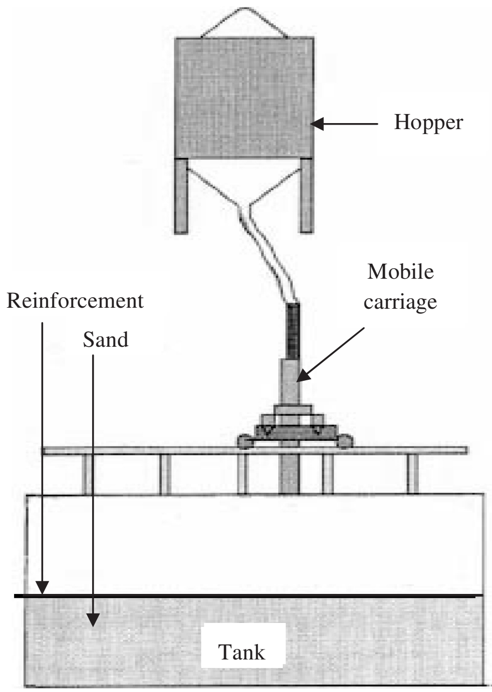

Figure 3. Pluviation system.

2.4 *Sensors*

Two types of incremental position sensors were used. A wire sensor placed in the front of the tank, allowing measuring displacements of the strip and LVDT sensors, placed on supports at the tank rear, allowing measuring displacements along the reinforcement. In order to avoid any friction effect with sand during the extraction test, these cables are threaded in Teflon sheaths. To measure the tensile force, an annular load sensor is placed at the end of the extraction jack.

2.5 *Pluviation system*

The pluviation method is defined as a technique of granular sample reconstitution by material discharge.

Among other techniques, it allows the control of the density of the sand set up and to simulate the reconstitution of a sandy ground formed by sedimentation. An automatic system, double axis, allowing that the whole tank surface was set up. It is remoted by a computer and moves at constant speed in the two directions of the tank. A hopper is placed above the tank and connected by a flexible pipe to a mobile carriage being on the automatic axis system. Sand runs out of the hopper towards the carriage by the means of a ring of diameter equal to 20 mm. This system makes it possible to control the flow of sand. An adjustment, making it possible to obtain a density of approximately 1.55, was selected by L. Martinez & B. Novelli (2006).

3 TESTS

3.1 *Procedure*

The operation starts with the filling of the tank with the pluviation system. Then, the reinforcement strips, equipped with the sensors, are installed before the total filling and the closing of the tank. In order to apply an overload similar, we inflate the air cushion to a pressure equivalent to a height of fill.

The tests were carried out at an extraction speed of 1 mm per minute.

3.2 *Test routine*

Nine tests were carried out on the two types of reinforcements at various levels of surcharges. Five tests on the geosynthetic strips and four tests on the steel strips. Concerning the geosynthetic straps, the tests were doubled for each load level to obtain better results.

4 ANALYSIS AND EXPLOITATION

The tests made it possible to determine the tension load, the maximum friction parameter mobilized as well as displacements in several points of the strips. These results (tables 2 and 3), show that the friction parameter decreases with the increase on loads on the two types of reinforcement. This behavior is related to the dilatancy decrease of the ground with the increase of the vertical pressure. For the geosynthetic straps, with a pressure of 50 kPa, the friction parameter is equal to 0.81 (slightly higher than $\tan(\phi)$ for $\phi = 38°$) and for a pressure of 100 kPa, it is equal to 0.74 (lower than $\tan(\phi)$). These values are higher than the results obtained from smooth steel reinforcements pull-out tests carried out by Alimi (1977) on small-scale model. However, better results were obtained for higher densities ground. The grading limits of soil presents also an influence on the dilatancy soil and consequently on the friction parameter. This last increases with the increase on grading limits of soil. It is also necessary to note that in the tank, the geosynthetic strip is placed on a relatively plane surface whereas in a actual work it is placed on an irregular surface of the ground, which increases its adherence.

The analysis of the behavior of the two types of reinforcement (figure 4) shows that the steel strip starts to move over all their length, as soon as a load is applied at the head. Displacements in the medium and the rear of the strip are close to displacement at the head and friction is mobilized uniformly on the reinforcement. However, in the case of the polyester strips, the tension

Table 2. Summary of the test results obtained on the synthetic strips.

Test	1	2	3	4	5
Vertical stress (kPa)	50	50	75	100	100
Maximum tension (kN)	16.44	15.46	22.5	28.17	28.27
Tensile stress (kPa)	43.26	40.68	59.21	74.13	74.39
friction parameter	0.87	0.81	0.79	0.74	0.74
friction Angle(°)	40.9	39.1	38.3	36.6	36.6

Table 3. Summary of the test results obtained on the steel strip.

Test	6	7	8	9
Vertical stress (kPa)	50	75	100	120
Maximum tension (kN)	14.09	20.9	24.03	27.7
Tensile stress (kPa)	74.16	110	126.47	145.8
friction parameter	1.48	1.47	1.26	1.21
friction Angle(°)	56.0	55.7	51.7	50.5

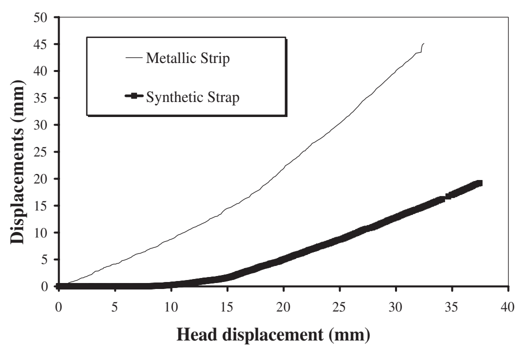

Figure 4. Displacement of the points located at the center of the steel strip and of the polyester strap (confining stress equal to 50 kPa).

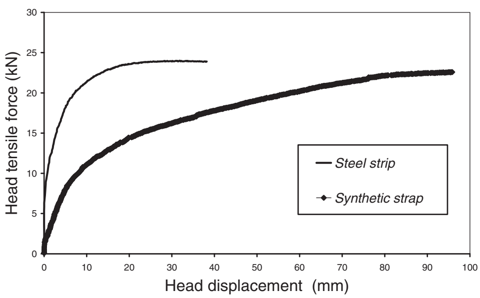

Figure 5. Tensile force at the head of steel and synthetic strips (loading constraint equal to 100 kPa).

Table 4. Effort mobilized for a displacement at the head of 1% inclusion length.

Test	Uh	T′ (kN)	T (kN)	T′/T
5	19(mm)	17.32	28.30	0.61
8	19(mm)	23.45	24.01	0.98

T'. Tensile force for 19 mm of the head displacement. T. Tensile force at saturation of friction strength. Uh : Displacement at the head of the strip.

in the strip is gradually mobilized with the increase of the tension at the head of the strip. Friction is thus mobilized gradually along the band and displacement at the head is requested for low tensile stresses (figure 5). This behaviour is anticipated by Segrestin & Bastick (1996).

Table 4 highlights the difference in tension/displacement curves between the two types of reinforcement for the same displacement at the head of the strip.

The steel strip makes it possible to work at loads levels of order of magnitude as those taken again by a surface of Omega band twice higher. The ratio between the 50 mm wide steel strip friction parameter and the one for two parallel 50 mm polyester strips varies between 1.7 and 1.8.

5 CONCLUSIONS

The results obtained from the pull-out tests highlight that the steel strip friction is slightly higher than the Omega strip friction. These results highlight two differences on these two types of strips: in the load curve (tension versus displacement) as well as the displacements delay in the geosynthetic strip. In fact, the steel strip starts to move over all their length, as soon as a load is applied at the head and friction is mobilized uniformly on the reinforcement. While, in the case of the synthetic strips, the tension and the friction are mobilized gradually along the strip. The behaviour difference of the two types of reinforcement, confirms that it is necessary to develop new design methods more adapted for the structures reinforced by extensible reinforcements. The analytical modeling of displacement curves versus tension, using the test results, will make it possible to define the interaction law between the ground and geosynthetics and to develop the knowledge for a new design method.

In fact, this article is an introduction to an ambitious research work of the reinforced earth structures behavior and which is the subject of collaboration between the LGCIE laboratory of the INSA Lyon and the *Terre Armée Internationale*. Within the framework of this collaboration, a doctorate thesis is currently in progress. The subject of this thesis is around three principal axes. An experimental axis aims to perform pull out laboratory tests in a test tank and to instrument in situ reinforced earth structures in order to understand the operation mechanism of this soil mass and to validate numerical calculations. A numerical part of the research will permit us to better understand the influence of various parameters and to use a new structure safety approach. Finally, the seismic impact on structure will be studied. Dynamic approach can be completed by a comprehensive study of the structures under dynamic loading of TGV type.

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