Laboratory Study of Sand Liquefaction by the Insertion of Geosynthetics

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ABSTRACT: The Geology and Mechanics Laboratory of the University of Grenoble has for some years been undertaking research into the behaviour of soils reinforced with geosynthetics subjected to liquefaction.
This paper analyses the results of these tests on sand of the Hostun "RF" type, with or without geotextiles - geomembranes. The results obtained demonstrate the role that these types of inclusions can play depending on their characteristics. In addition, an optimum ratio between geosynthetics and soil has been determined.
This study also showed the quantitative and qualitative benefits of geosynthetic inclusions in delaying liquefaction and thus in increasing the safety of earth embankments.

1. INTRODUCTION

In many cases, reports drawn up by experts on areas damaged by an earthquake show that the phenomenon of soil liquefaction gives rise to considerable damage. It would therefore seem important to obtain a clearer understanding of the behaviour of soils subject to seismic stresses in order to find solutions for delaying the onset of liquefaction. The research work conducted by the Geology and Mechanics Laboratory was guided and motivated by these facts and by the increased use of geosynthetics in civil engineering works.

The article which follows gives an account of the general role that a geotextile type inclusion can play in this context.

2. EQUIPMENT AND MATERIALS USED

The experimental equipment consisted of a "conventional" triaxial cell for samples of 70 mm diameter, which is fixed to a 20 kN capacity cyclic triaxial press. This assembly is subject to axial stresses. The parameters recorded for a constant confining stress are: time, displacement, force and interstitial pressure. The reference soil is a Hostun sand of the "RF" type. The geotextiles and geomembranes used are described in the following sections.

3. INFLUENCE OF RELATIVE DENSITY AND INITIAL TEST CONDITIONS

During a preliminary study concerning the effect of relative density on liquefaction resistance, with or without the presence of a geotextile (Rd = 56.2% or Rd = 87.5%), the following points were observed. For the higher relative density, the geotextile had little effect on the liquefaction resistance. On the other hand, for the lower relative density, the geotextile led to a considerable improvement in this resistance. As a result, only this lower relative density value was considered in subsequent tests.

These tests were performed with the following parameters:

- relative density Rd = 56.2%, corresponding to a dry density value of $\gamma_d = 15$ kN/m^3,
- a frequency of 0.5 hertz,
- a Skempton coefficient B at least equal to 0.95.

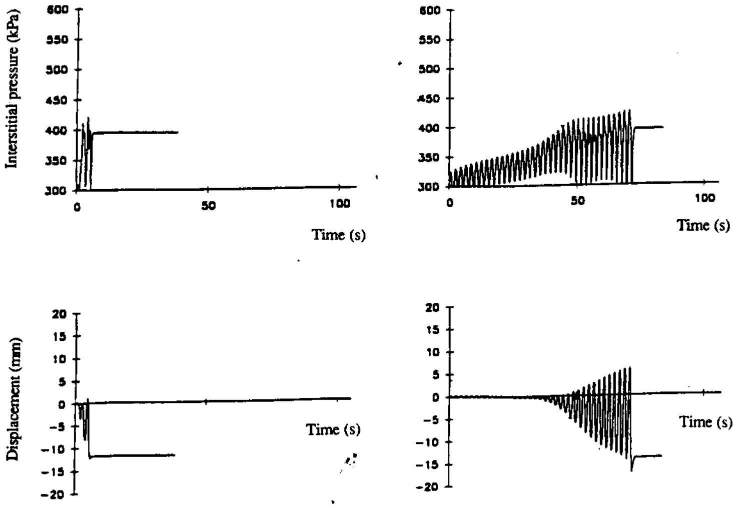
On the other hand, the cyclic deviatory stress and the confinement pressure were varied.

4. COMPARATIVE STUDY BETWEEN REINFORCED AND A NON-REINFORCED SAMPLES DURING A LIQUEFACTION TEST

Figure 1 shows the results obtained during a liquefaction test, first with a reinforced sample and then with a non-reinforced sample.

The inclusions in the reinforced sample consisted of three sheets of non-woven geotextile (sand bed distribution at 1/6, 1/3, 1/3, 1/6 of the sample height). The tests were carried out under the following conditions: cyclic deviatory stress equal to 52 kPa, confinement stress of 400 kPa and a counter pressure of 300 kPa.

For the non-reinforced sample, liquefaction was obtained in a very short time (3 - 5 cycles). However, liquefaction of the sample reinforced with the three geotextile sheets was considerably delayed. The favourable role played by the geotextile inclusions was thus clearly shown. An attempt is made below to explain the mechanism involved and to set the limits.



NON-REINFORCED SAMPLE

SAMPLE REINFORCES with three sheets (NTb3)

Figure 1: Resistance to liquefaction of reinforced and non-reinforced samples.

5. LIQUEFACTION TESTS WITH DIFFERENT TYPES OF GEOTEXTILES AND GEOMEMBRANES

Liquefaction tests were carried out in order to study the behaviour of samples reinforced with different types of geotextiles and geomembranes. The aim of this study was to demonstrate the qualitatively the mechanical and hydraulic aspects of the inclusion influencing the resistance to liquefaction.

Initially, an in-depth study of the first loading-unloading cycle was carried out on non-reinforced samples (Table 1).

Table 1 Variation in interstitial pressure and displacement as a function of deviatory stress during the first cycle.

	Case a	Case b	Case c
Deviator (kPa)	41.6	46.8	52.0
dU (kPa)	- 4	+ 0.5	+ 30
dI (kPa)	- 0.095	- 0.160	- 0.445

The cycle is made up of two stages: compression followed by expansion. The most significant variations in interstitial pressure and displacement occur during the expansion stage. In case (a) for example, no interstitial overpressure is noted because the vertical expansion of the sample is accompanied by a corresponding expansion of the material. On the other hand, in cases (b) and (c), a reduction in sample diameter occurs. An increase in interstitial pressure ($du > 0$) is observed in parallel with the vertical expansion and this reflects horizontal shortening. As shown in table 1, this shortening effect increase with deviatory stress. Consequently, in order to increase the resistance to liquefaction, ways must be found to restrict the increase in interstitial pressure and the horizontal contraction of the sample when subjected to the expansion stage.

In view of the above remarks, different types of inclusions were selected, characterised by different values of rigidity, compressibility and surface condition in order to gain a better understanding of the role played by these parameters.

A number of observations can be made in the light of the liquefaction tests performed on sand samples reinforced with different geotextiles and geomembranes, as shown on Fig. 2.

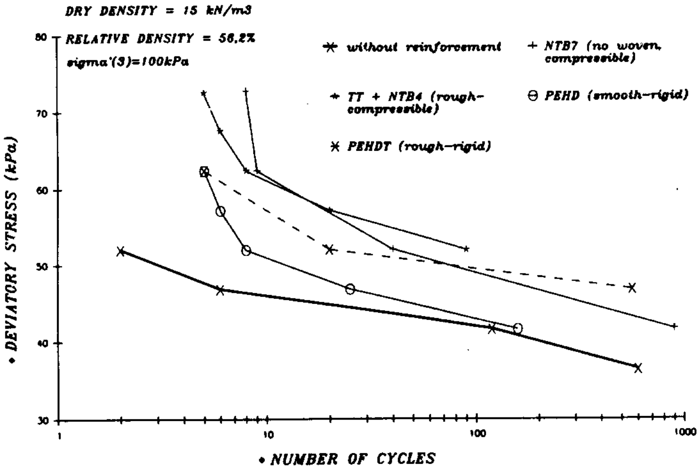


Figure 2: Influence of soil-geotextile or soil-geomembrane interface on the resistance to liquefaction.

The initial conditions of these tests are an effective confining stress of $\sigma'_3 = 300$ kPa ($\sigma_3 = 400$ kPa, $u = 100$ kPa).

In the case of high deviatory stresses, the increase in resistance to liquefaction is promoted by an enhanced expansion potential and higher geotextile roughness (for example: the non-woven b7 sample (NTb7) gives better performance than the PEHDT geomembrane). The same cannot be said for low deviatory stresses for which the rigidity of the inclusion plays a major role.

For the different liquefaction tests performed, it can be concluded that in cases of high deviatory stresses and small number of cycles (similar to those occurring in an earthquake situation), the expansion potential plays a dominant role. However, the rigidity and surface condition must not be ignored.

6. DETERMINATION OF OPTIMUM AMOUNT OF GEOTEXTILE ON LIQUEFACTION RESISTANCE

Following the various interpretations concerning the role of geotextiles, it seemed interesting to highlight the optimum effect of geotextiles with regard to liquefaction resistance.

This series of tests was carried out under an effective confining stress $\sigma'_3 = 100$ kPa. The geotextile used was a non-woven b7 (NTb7) laid in horizontal sheets. The number *n* of sheets varied from one to four. Figure 3 shows that the liquefaction resistance is directly proportional to *n* as long as *n* remains less than or equal to 3. For four sheets, however, the phenomenon was reversed and it was found that this additional sheet had an adverse effect.

It therefore seems reasonable to talk of an optimum amount of geotextile with respect to liquefaction resistance.

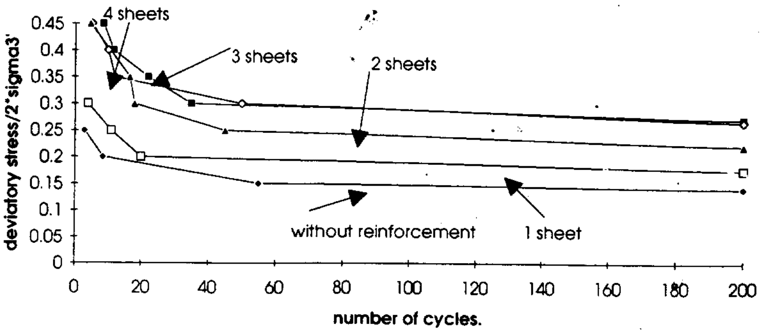


Figure 3: Liquefaction resistance as a function of number of sheets.

An attempt has been made to interpret this phenomenon from figure 4. It is worth recalling the two main features of the geotextile placed horizontally in the sample during a cycle.

During the compression half-cycle, the geotextile tends to contract as it is much more compressible than the soil. The liquefaction resistance is not improved. On the other hand, during the expansion half-cycle, a high degree of expansion is observed and this has a favourable effect on the liquefaction resistance.

In the case of four geotextile layers, the increase in interstitial pressure during the compression stage is very high given the considerable compressibility of the sample, and despite an expansion potential during the expansion stage greater than that of samples reinforced with three sheets. At the end of the cycle, the interstitial pressure is about the same for both tests.

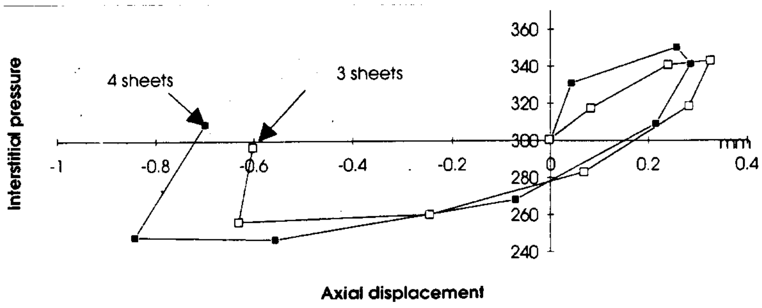


Figure 4: First test cycle with 4 sheets and 3 sheets of non-woven b7 geotextile (NTb7) for a deviatory stress of 80 kPa.

7. INFLUENCE OF GEOTEXTILE SHEET POSITION WITHIN THE SAMPLE.

The preceding section showed that there is an optimum amount of geotextile with regard to liquefaction resistance. In addition, the geotextile sheeting is laid according to a sand bed distribution of 1/6, 1/3, 1/3, 1/6 of the sample height. What about other potential sheet arrangements? Previous work (Richa, B., 1992) has indicated that when the same volume of geotextile is used, but placed in the form of chippings (fragments of geotextile with largest dimension not exceeding 10 mm, mixed with the sand), the liquefaction was lower compared to the sample with three full sheets.

Figure 5 illustrates the first cycle of liquefaction resistance for two tests performed with an effective confining stress of $\sigma'_3 = 100$ kPa. The geotextile used is a non-woven b7 (NTb7). Test 1 with three sheets of geotextile placed at the bottom of the sample and test 2 with a sand bed distribution of 1/6, 1/3, 1/3, 1/6 of the sample height.

Test 1 gave a higher compressibility than test 2 (in one case there is a single soil-geotextile contact while there are six contacts in the other case, and it is known that a soil-geotextile contact reduces the compressibility compared to a geotextile-geotextile contact):

At the end of the first loading-unloading cycle, the interstitial pressure was found to be lower in test 1 than in test 2. However, the axial deformation is slightly high in test 1.

This means that the horizontal arrangement of the sheeting with respect to the height of the sample does not have any effect on liquefaction resistance.

The compressibility factor was compensated for by the sheet arrangement parameter. The sample in test 1 was more compressible than that in test 2, but the latter is more rigid and thus less deformable.

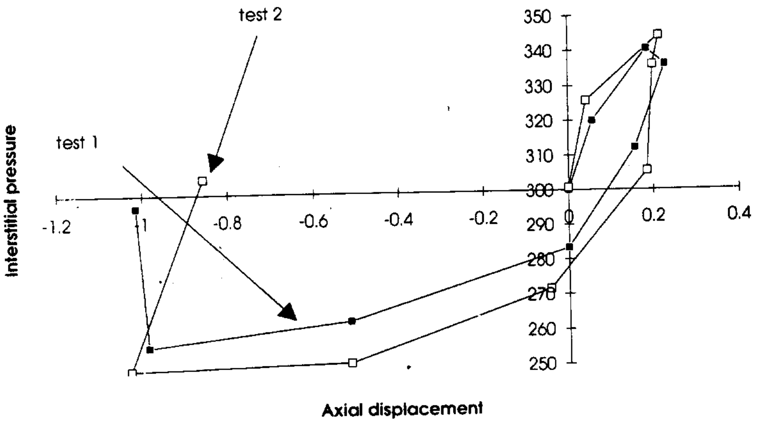


Figure 5: First cycle of two tests with different arrangement of the geotextile sheeting.

8. CONCLUSIONS AND PROSPECTS

This study has highlighted the role played by a geotextile - both qualitatively and quantitatively - with respect to the liquefaction resistance of a soil.

Moreover, parallel studies (Richa, B., 1992) have shown that the installation of vertical sheets gave less satisfactory results than sheets placed horizontally with a surface ratio of 0.81 between vertical sheets and horizontal sheets.

It would be of interest to extrapolate this study to real-life conditions in order to assess the improvements that could be achieved on a liquefiable site by the addition of geotextile strips.

RÉFÉRENCE

Richa, B (1992) Etude au triaxial dynamique de la liquéfaction des sols renforcés par géotextiles. Doctoral thesis, IRIGM-LGM, University J. Fourier - Grenoble 1.