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Dynamic analysis of geosynthetic interfaces by shaking table tests

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ABSTRACT: The static and dynamic friction offered by different geosynthetic/geosynthetic interfaces has a very important role in the analysis of landfill behaviour, for which reason the use of geosynthetics is increasing more and more. In the present paper some interfaces including geomembranes, geotextiles and geosynthetic clay liners (GCL) are investigated by means of shaking table tests, using the shaking table available at the University of Catania. The dynamic horizontal excitation is a sinusoidal variable input, for which the effects of the maximum amplitude and the frequency content are investigated. Moreover, a time-history accelerogram, recorded in Catania during the 13 December, 1990 earthquake, is used as input excitation. The experimental results are reported in terms of time-histories of accelerations and relative displacements, in order to investigate the acceleration transfer through the interface and the geosynthetic/geosynthetic relative displacement.

1 INTRODUCTION

The continuous growth of waste quantity, as well as the awareness of environmental protection, lead to the improvement of landfill design and to the spreading of "new ecological" landfill building (De Vita & Arnold, 2001). Geosynthetics are extensively used in the cover and bottom barrier systems of new landfills, with various functions: geomembranes and geosynthetic clay liners (GCL) are used as hydraulic barriers, geotextiles for separation and filtration, geogrids for reinforcing and geocomposites for drainage. Landfill design is essentially based on groundwater contamination due to leachate leakage. An optimal functionality not only of the hydraulic barrier systems but also of the filtration and drainage systems, as well as the stability of the whole landfill, are necessary to minimise the leachate leakage site specific risk. In seismic zones the leachage leakage site risk must be matched to the seismic risk of the zone.

From a mechanical point of view, a knowledge of the frictional behaviour between the geosynthetics is essential for an assessment of the stability of the inclined sealing systems. For a long time laboratory tests, as well as numerical analysis (Carrubba et al., 2001; Massimino et al., 2001) and monitoring of full scale landfills, have been performed ever more frequently.

As far as the laboratory tests are concerned, the static ones, performed above all with direct shear and ring shear devices, pull out box and tilt table apparatus, have been widely performed (Negussey et al., 1989; Jones & Dixon, 2000). The dynamic laboratory tests are less frequent, even if the dynamic interface behaviour is very interesting and sometimes unpredictable. The dynamic tests are generally performed by means of direct or torsional cyclic shear devices, large scale shaking table or small shaking table placed on a centrifuge (De & Zimmie, 1999).

The paper presents the results of some large scale shaking table tests performed using geomembrane/geotextile and geomembrane/GCL interfaces. The investigated interfaces are commonly used in landfill bottom barriers; the geomembrane/geotextile interface is also frequently used in landfill cover barriers. In particular, smooth geomembranes lead to an easier slippage. The maximum amplitude and frequency content of sinusoidal input excitations are investigated in terms of acceleration transfer through the interface and geosynthetic/geosynthetic relative displacement. Finally a real time-history acceleration regarding the 13 December, 1990, Catania earthquake is used as input excitation.

2 EQUIPMENT

The shaking table device, available at the geotechnical laboratory of Catania University is shown in Fig. 1. It consists of a steel plate, 2.0 m long, 1.0 m wide and 0.08 mm thick, supported by four frictionless wheels constrained to move on rails, in order to restrict the motion only horizontally along the longest side of the table. The motion is provided to the table by a loading system consisting of a hydraulic actuator with the capacity to transfer a maximum static, horizontal force of 30kN and a maximum dynamic, horizontal force of 25kN, with the possibility to vary the load frequency as desired and the displacement amplitude up to 25 mm. The load system is controlled by an electronic system to pilot the actuator in LVDT mode.

A wooden test platform, 0.7 m long 0.7 m wide and 0.1 m deep, rests on the table. At the base of the platform a layer of geosynthetic is attached; the second layer of geosynthetic is at-

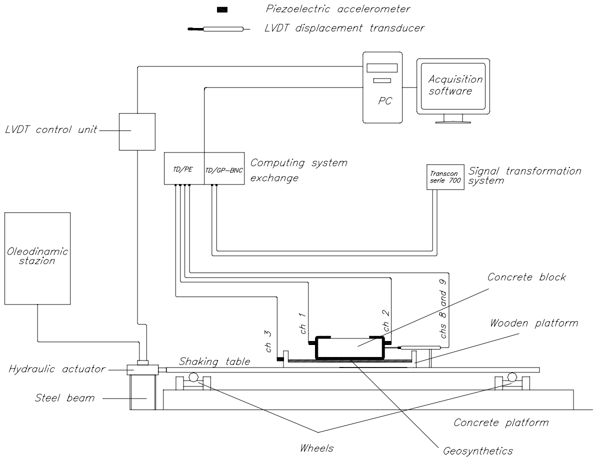

Figure 1. Shaking table frontal view and schematisation of the recorder instrumentation system.

tached to a concrete block, 0.50 m long 0.25 m wide and 0.10 m thick, as shown in Fig. 2. This system allows the evaluation of the dynamic frictional properties between the two layers of geosynthetics. The vertical load on the geosynthetic/geosynthetic interface is given by the weight of the concrete block, equal to 0.30 kN, and adding some steel plates of 0.10 kN each, up to a maximum vertical load of 1.30 kN. All the tests reported in the paper concern a vertical load equal to 0.40 kN.

The recording instrumentation consists of three piezoelectric accelerometers and two LVDT displacement transducers (Fig. 2). Two accelerometers are fixed to the opposite vertical sides of the block and one is fixed to the table. The LVDT displacement transducers, located along the shorter side of the block, allow the measurement of relative displacements between the table and the block and of eventual torsional block movements around the vertical axis. All the recording instruments are connected to a data acquisition system, consisting of a computing system exchange and a data processing software.

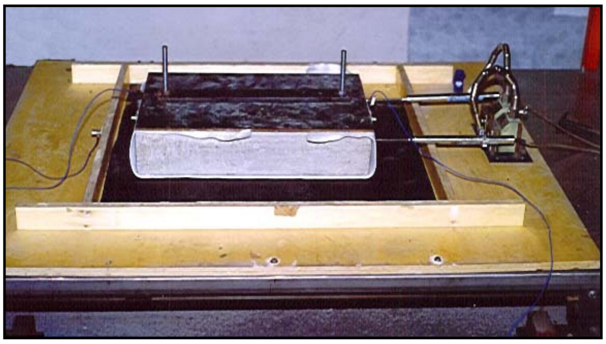

Figure 2. Geosynthetic allocation and instrumentation set-up (geomembrane-geotextile interface).

3 GEOSYNTHETIC/GEOSYNTHETIC INTERFACES

The following two geosynthetic/geosynthetic interfaces are considered:

- geomembrane - geotextile
- geomembrane - geosynthetic clay liner (GCL)

Both these interfaces are commonly used in landfill bottom barriers; the first one is also frequently used in landfill cover barriers. The main properties of the utilised geosynthetics are reported in Table 1. The geomembrane is a smooth HPDE geomembrane; the geotextile is a non-woven PP geotextile and the geosynthetic clay liner consists of a bentonite layer sandwiched between two woven PP geotextiles. The geosynthetic attached to the wooden platform is 0.7 m long and 0.7 m wide, the geosynthetic attached to the concrete block is 0.7 m long and 0.3 m wide.

Table 1. Main geosynthetic properties.

Type	geomembrane	Geotextile	GCL
Polymer type	HPDE	PP	PP
Thickness (mm)	2.5	3.0	6.0
Tensile strength (kN/m)	69	18	23-24
Strain to peak strength (%)	700	78	11-13

4 EXPERIMENTAL RESULTS

First of all the geomembrane/geotextile interface is taken into account. Two sinusoidal displacement inputs are applied to the table. The first one (Fig. 3) is characterised by a frequency of 5 Hz and a displacement amplitude which increases continuously in the first 30 cycles up to a value of 4 mm, then decreases in other 30 cycles up to zero.

Fig. 3 reports the time-histories of the table acceleration, the block acceleration and the relative displacement between the table and the block. Until no table-block relative displacement occurs, i. e. no slippage occurs, the block moves together with the table. When the interface friction is achieved a relative displacement occurs. According to the Coulomb failure mechanism at the geosynthetic/geosynthetic interface, the minimum acceleration, which leads to a relative displacement, named also "critical acceleration" ($a_{crit.}$), gives the dynamic friction coefficient ($tan\ \phi_{dyn}$) of the geosynthetic/geosynthetic interface:

$$tan\ \phi_{dyn} = a_{crit.} / g \qquad (1)$$

being g the gravity acceleration.

For the case reported in Fig. 3 the critical acceleration is equal to about 0.30 g, i. e. $\phi_{dyn} \approx 17°$. Overcoming this value, an accumulation of the relative displacement can be observed up to a permanent final value of 3.1 mm. The accumulation of the relative displacement cannot be evaluated with the typical Coulomb frictional contact theory; a dynamic analysis must be performed taking into account the elasto-visco-plastic behaviour of the interfaces.

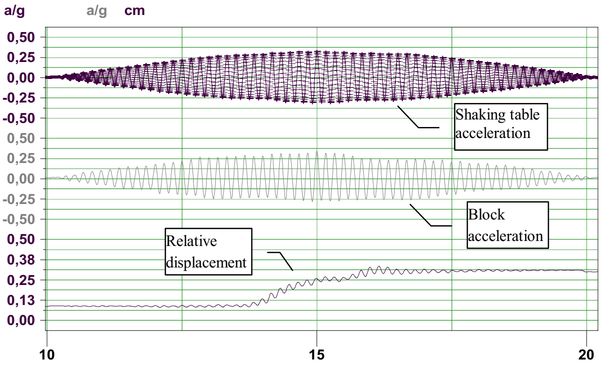

Figure 3. Shaking table test results for the geomembrane/geotextile interface with a sinusoidal input of 5 Hz and a maximum displacement of 4 mm.

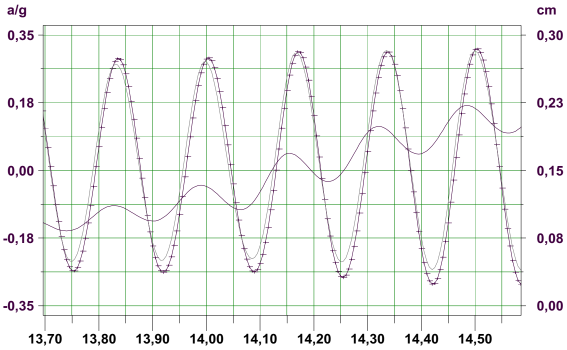

Figure 4. Restricted time interval response for the case reported in the previous figure 3.

In the case of Fig. 3 the table acceleration and the block acceleration continue to be substantially in phase, even after the occurrence of geomembrane/geotextile slippage. Fig. 4 shows the acceleration and displacement time-histories in the short time interval of 13.70 - 14.50 s, i. e. when the accumulation of the relative displacement occurs.

Another geomembrane-geotextile interface is subjected to an exciter displacement sinusoidal time-history characterised by a frequency of 7 Hz and an amplitude which increases from zero to the maximum value of 3 mm during the first 7.5 sec, then remains constant for 15 sec, finally decreasing to zero in 7.5 sec.

The time-histories of the recorded accelerations and displacement are plotted in Fig 5. In this case the critical acceleration is equal to about 0.37 g, i. e. $\phi_{dyn} \approx 21°$. The permanent displacement is equal to about 35.0 mm. Most of the features of the previous test can be recognised even for this test, but some different behaviour is observed in this case. When slippage occurs the block acceleration reaches values greater than that of the table acceleration and the table and block acceleration time-history phases become different (Fig. 6).

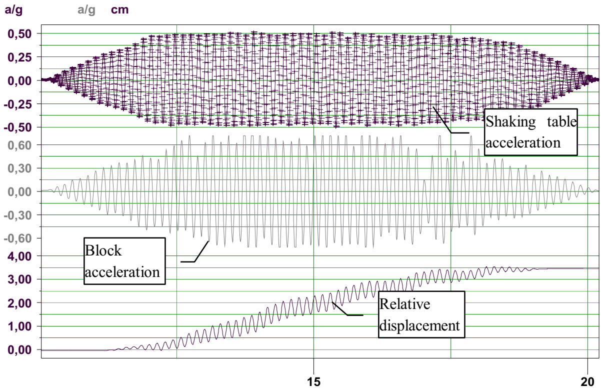

Figure 5. Shaking table test results for the geomembrane/geotextile interface with a sinusoidal input of 7 Hz and a maximum displacement of 3 mm.

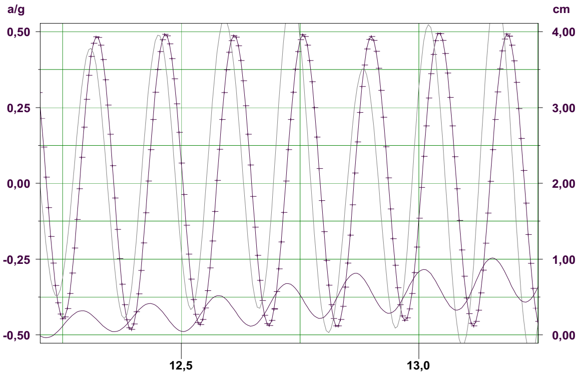

Figure 6. Restricted time interval response for the case reported in the previous figure 5.

Geomembrane/GCL systems are subjected to input motions similar to those applied to the geomembrane/geotextile systems. In a first case a sinusoidal displacement input, increasing continuously up to the value of 4 mm and then decreasing continuously to zero, is applied. The input frequency is fixed equal to 5 Hz. The time-histories of the table and block accelerations, as well as of the table-block relative displacement, are reported in Fig. 7. In this case the critical acceleration is equal to about 0.30g, i. e. $\phi_{dyn} \approx 17°$. The permanent displacement is equal to about 2.9 mm. As in the case reported in Figs. 3 and 4, after the slippage the block acceleration shows values less than those of the table acceleration. No phase difference can be noted between the time histories of the block and table accelerations (Fig. 8).

A second geomembrane/GCL interface is subjected to an exciter displacement sinusoidal time-history characterised by a frequency of 8 Hz and an amplitude which increases from zero to the maximum value of 2 mm during the first 7.5 sec, then remains constant for 15 sec, finally decreasing to zero in 7.5 sec. The time-histories of the recorded accelerations and displacement are plotted in Figs. 9 and 10. The critical acceleration is equal to about 0.37 g, i. e. $\phi_{dyn} \approx 21°$. The permanent displacement is equal to about 20.0 mm. It must be stressed that most of the features of the test reported in Figs. 5 and 6, which regard the geomembrane/geotextile interface, can be recognised. The similarity could be very probably due to the input features. As for the case reported in Figs. 5 and 6, even in the case reported in Figs. 9 and 10 when slippage occurs the block acceleration reaches values greater that those of the table acceleration and the table and block acceleration time-history phases become different. Finally, in both the cases a considerable permanent displacement is reached, differently from the cases reported in Figs. 3 and 4 and in Figs. 7 and 8. The accumulation of a considerable permanent displacement could be due to the different nature of the sinusoidal input motion: for the cases reported in Figs. 3 and 4 and 7 and 8 the maximum amplitude is reached only at 15 sec, i. e. for the cycle of maximum amplitude; while for the cases reported in Figs. 5 and 6 and 9 and 10 the maximum amplitude remains constant for 15 sec, i. e. for many cycles. This last condition leads to a stronger displacement accumulation effect.

To complete the test program a geomembrane/GCL system is also subjected to a real dynamic input, which is the E-W component of the acceleration recorded in Catania during the 13 December, 1990 earthquake. Fig. 11 shows the seismic input, while Fig. 12 shows the block acceleration time-history and the relative displacement time-history. For this test it is possible to observe that, even if the earthquake was moderate, with an acceleration at bedrock of 0.1 g and a maximum recorded acceleration of about 0.25 g in Catania, a significant slippage occurs. The relative displacement alternates time intervals of negative values to time intervals of positive values, reaching the maximum value of about 7.7 mm. However, at the end no permanent displacement exists. Moreover, time intervals of no relative displacement and time intervals of a sudden increase or decrease of the relative displacement can be observed.

Comparing the table and block acceleration it is possible to note a slight increase of the block acceleration in respect of the table acceleration, especially in the initial phase; moreover the block acceleration time-history has a frequency content higher than that of the table acceleration time-history.

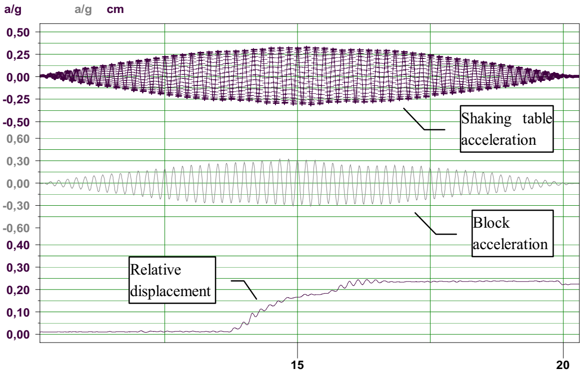

Figure 7. Shaking table test results for the geomembrane/GCL interface with a sinusoidal input of 5 Hz and a maximum displacement of 4 mm.

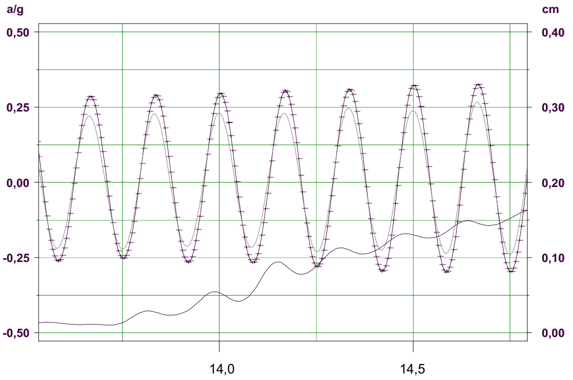

Figure 8. Restricted time interval response for the case reported in the previous figure 7.

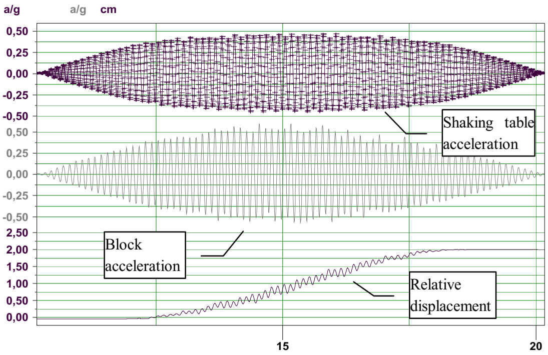

Figure 9. Shaking table test results for the geomembrane/GCL interface with a sinusoidal input of 8 Hz and a maximum displacement of 2 mm.

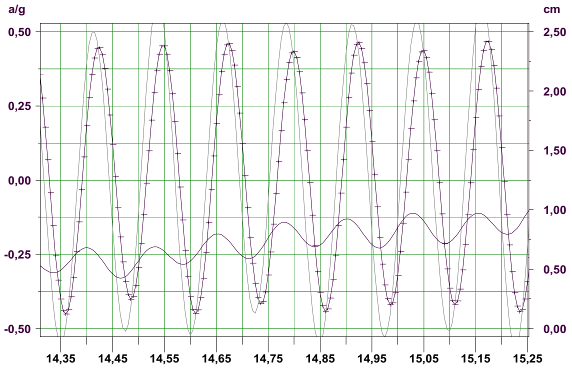

Figure 10. Restricted time interval response for the case reported in the previous figure 9.

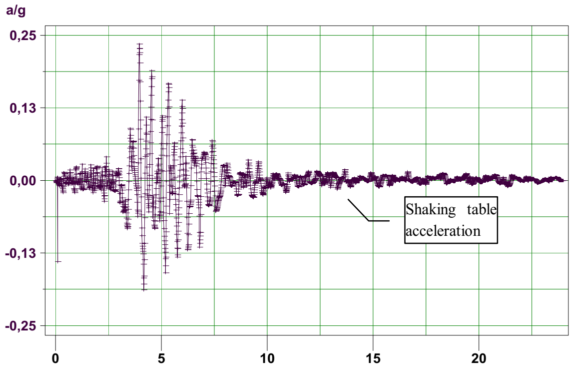

Figure 11. 13 December, 1990 E-W component acceleration time-history used for the geomembrane-GCL interface.

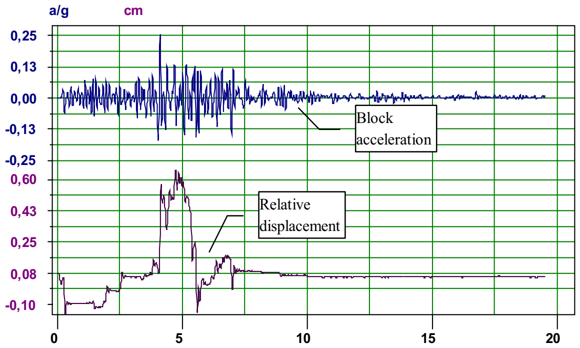

Figure 12. Shaking table test results for the geomembrane/GCL interface characterised by the input acceleration reported in figure 11.

5 CONCLUSIVE CONSIDERATIONS

The dynamic friction behaviour of geomembrane/geotextile and geomembrane/GCL interfaces is investigated by means of shaking table tests. Sinusoidal input motions of different types, frequencies and amplitudes are applied to the table. Finally the E-W component of the acceleration recorded in Catania during the 13 December, 1990 earthquake is considered. Analysing the results it is possible to note that the dynamic friction angle is affected by the frequency and the amplitude of the input motion. Low frequency and high amplitude lead to dynamic friction angles considerable less than those related to high frequency and low amplitude. Moreover, with low frequency and high amplitude input the block acceleration achieves values less than those of the table acceleration, showing an isolation effect, already investigated by many researchers (Yegian et al., 1999); on the contrary with high frequency and low amplitude input, the block acceleration achieves greater values.

The considerable permanent displacement could be due to the different nature of the sinusoidal input motions: when the maximum amplitude is reached only for one cycle the permanent displacement is of some millimetres; when the maximum amplitude remains constant for many cycles the permanent displacement is of some centimetres. No permanent displacement occurs considering a real acceleration time-history, even if a maximum relative displacement of 7.7 mm is achieved. It must be stressed that this displacement is related to a moderate earthquake, significantly less severe than the scenario earthquake estimated for Catania, having a maximum acceleration of 0.32 g at bedrock (Pessina, 1999).

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