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Large scale ramp tests on soil-geosynthetic systems

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ABSTRACT: This paper presents an experimental investigation on the use of geogrids buried in cover soils of slopes of waste disposal areas using a large-scale ramp test. The tests involved the use of geogrids with varying values of tensile stiffness and geometry installed at different elevations above a geomembrane layer resting on the ramp surface. The performances of smooth and rough geomembranes were also assessed. The results show that the presence of a geogrid in the cover soil increases the ramp inclination at failure, reduces the tensile forces mobilised in the geomembrane and the deformability of the system. Factors such as the geometrical characteristics and tensile stiffness of the geogrid and roughness of the geomembrane affect the behaviour of the system.

1 INTRODUCTION

Slopes of waste disposal areas, channels and reservoirs can be composed of several layers of geosynthetics with different functions, such as drainage, filtration, barrier, protection or reinforcement, as schematically shown in Figure 1. Lack of adherence between layers can yield to failure along soil-geosynthetic or geosynthetic-geosynthetic interfaces. Thus, it is utmost importance a proper evaluation of interface resistances in such works.

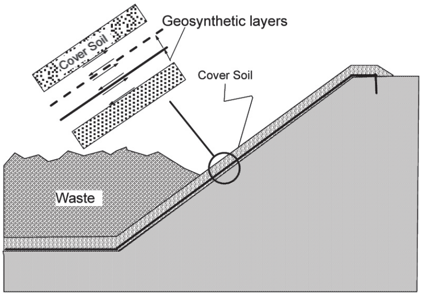

Figure 1. Multi-layers of soils and geosynthetics in slopes of waste disposal areas.

The ramp test can be used for the evaluation of soil-geosynthetic or geosynthetic-geosynthetic adherence and one of its advantages is that tests under low stress levels can be conducted. Besides, the test is quick and simple to perform.

Several works can be found in the literature on the use of the ramp test for the study of soil-geosynthetic interaction, with varying equipment characteristics and dimensions (Girard et al. 1990, Giroud et al. 1990, Girard et al. 1994, Gourc et al. 1996, Wasti and Özdüzgün 2001, Palmeira et al. 2002, Palmeira and Viana 2003, Viana 2003 and Palmeira et al. 2004).

In this work a large scale ramp test was used for the evaluation of the interaction between different soil-geosynthetic. The research programme involved the study on the influence of the elevation and geometry of a geogrid reinforcement installed in the cover soil on the reduction of soil displacements and stresses transmitted to an underlying geomembrane layer.

2 EXPERIMENTAL PROGRAMME

2.1 *Apparatus used in the tests and test arrangements*

Figure 2 shows the apparatus used in the ramp tests. The apparatus comprises a system with a ramp that can be inclined so as to cause failure along the interface between a soil layer confined in a rigid box and the geosynthetic layer resting on the ramp surface. Boxes of different heights can be used to confine the soils tested. By combining the heights of these boxes the elevation (h in Fig. 3) of the geogrid reinforcement with respect to the ramp surface can be varied. The

Figure 2. General view of the test apparatus.

internal dimensions of the boxes are 1920 mm (length) and 470 mm (width). The total height (H in Fig. 3) of the soil samples varied between 50 mm and 200 mm, depending on the test considered. The geosynthetic layers were fixed to the ramp extremity by clamps attached to load cells, which allowed measurements of loads mobilised in the geosynthetic layers during the tests. This arrangement aims to simulate the anchorage of the top extremity of the geosynthetic in a slope crest, for instance. The interfaces tested are long enough to minimise the influence of non uniform normal stress distributions on the test results, as discussed in Palmeira et al. (2002). The large dimensions of the area tested also allow the observation of progressive failure along the interface. The roughness of the ramp surface can be varied for the investigation of this parameter on the test results.

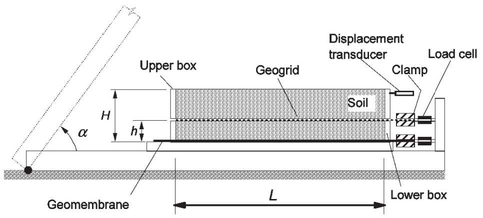

Figure 3. Test arrangement for a test with a geogrid in the cover soil (Palmeira and Viana, 2003).

The test is carried out by continuously increasing the inclination of the ramp with the horizontal direction up to the occurrence of failure along an interface. During ramp inclination the displacements of the upper box and forces in the geosynthetic layers are monitored by means of displacement and force transducers.

The tests conducted in the research programme described in this paper involved the investigation on the influence of the elevation and geometry of a geogrid installed in the cover soil on the forces mobilised in a geomembrane fixed to the ramp (Fig. 3) as well as on the displacements of the cover soil. The soil layer in the tests was 200 mm high, with no surcharge. The values of geogrid elevation (h) used were equal to 0, 5 cm, 10 cm and 15 cm.

2.2 *Soil characteristics*

A medium to coarse sand with particles diameters between 0.6 mm and 2 mm was used in the tests. Table 1 summarises the main characteristics of this soil. The sand particles are angular and the specimens were prepared with a relative density of 57%. Sand friction angles varied between 31° and 40°, depending on the stress level considered.

Table 1. Soil characteristics.

D_{10} (mm)$^{(1)}$	0.63
D_{50} (mm)	0.90
CU	1.61
Unit weight (kN/m^3)	14.5
Soil particle density	2.57
Relative density (%)	57
Friction angle (°)	31-40$^{(2)}$

Notes: (1) D_{10} and D_{50} = particle diameters for which 10% and 50% in weight are smaller than those diameters, respectively, CU = coefficient of uniformity (= D_{60}/D_{10}); (2) From direct shear tests; dependent on stress level; range of normal stresses values between 2 to 7 kPa.

2.3 *Geosynthetics characteristics*

The geosynthetics tested comprised 2 geomembranes and 2 geogrids. The main characteristics of the geosynthetics tested are presented in Table 2. Geomembranes GM1 and GM2 are HDPE products with the former being 1mm thick and smooth and the latter 2 mm thick and rough. Figure 4 shows a general view of geogrids GG1 and GG2. These are polyester grids with a polyethylene cover with different aperture dimensions.

Table 2. Geosynthetics characteristics.

Code	$M_A^{(1)}$ (g/m^2)	t_G (mm)	T_{max} (kN/m)	ε_{max} (%)	J (kN/m)
GM1	950	1.0	33	700	260
GM2	≥ 940	2.0	29	100	300
GG1$^{(2)}$	250	1.1	20	12.5	200
GG2$^{(3)}$	760	1.4	200	12	1670

Notes: (1) M_A = mass per unit area, t_G = thickness, T_{max} = wide strip tensile strength, ε_{max} = maximum tensile strain, J = wide strip tensile stiffness; (2) Aperture sizes equal to 20 × 20 mm; (3) Aperture sizes equal to 200 × 40 mm.

3 RESULTS OBTAINED

3.1 *Influence of the presence of geogrid reinforcement in the cover soil*

Figure 5 shows the variation of mobilised tensile forces in geomembrane GM1 versus ramp inclination for different values of the elevation of geogrid GG1. The presence of the geogrid reduces significantly the force mobilised in the geomembrane. The ramp inclination

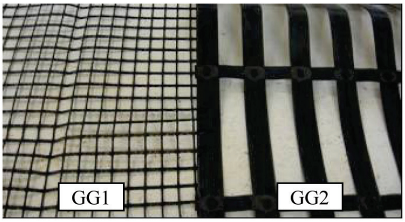

Figure 4. Geogrids used in the tests.

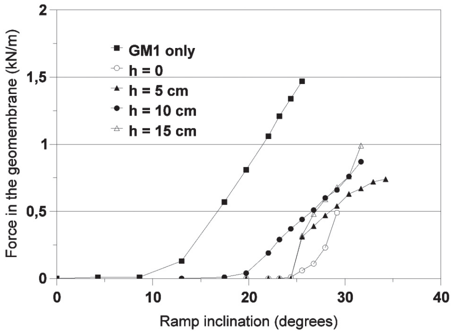

Figure 5. Force in the geomembrane versus ramp inclination and geogrid elevation.

at failure is significantly increased by the presence of the geogrid. For the test with no geogrid soil geomembrane interface failure occurred for a ramp inclination of 24°, while for tests with geogrid this value varied between 29° and 34°, depending on the grid elevation. These values represent increases in the ramp inclination at failure between 20% and 42% with respect to the situation without the geogrid.

The presence of the geogrid reinforcement also reduced the overall deformability of the system. In Figure 6 it can be seen that for a given ramp inclination the displacements of the top box with respect to the ramp surface were considerably smaller in the tests with geogrids in the cover soil.

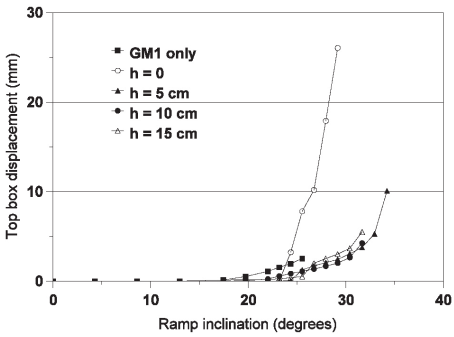

Figure 6. Top box displacement versus ramp inclination and elevation of the geogrid.

3.2 *Influence of grid geometrical characteristics on the stability of the system*

Geogrids GG1 and GG2 have different geometrical characteristics. The apertures in grid GG1 are 20 mm × 20 mm, whereas in grid GG2 they are 40 mm × 200 mm. The fraction of open area in grid GG1 is equal to 70%, whereas in grid GG2 this fraction is equal to 40%.

Figure 7 depicts the variation of ramp inclination at failure versus geogrid elevation for tests with geomembrane GM1 on the ramp surface and geogrids GG1 and GG2 in the cover soil. The result obtained in a test with geomembrane GM1 only is also presented for comparison. For both geogrids a marked increase in the ramp inclination at failure can be observed. In addition, for the range of geogrid elevations investigated geogrid GG1 performed better than geogrid GG2. At failure the soil slides on the geogrid surface. This favoured geogrid GG1, which has a greater fraction of open area than geogrid GG2.

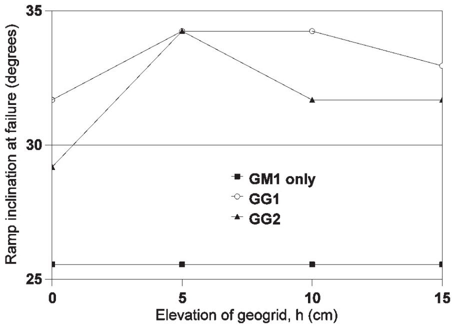

Figure 7. Ramp inclination at failure versus grid elevation (h).

Figure 8 shows that geogrid GG2 was more efficient than geogrid GG1 in reducing the tensile loads mobilized in the geomembrane immediately before failure of the system. It should be pointed out that the tensile stiffness of geogrid GG2 is considerably greater than that of geogrid GG1 (Table 2), which

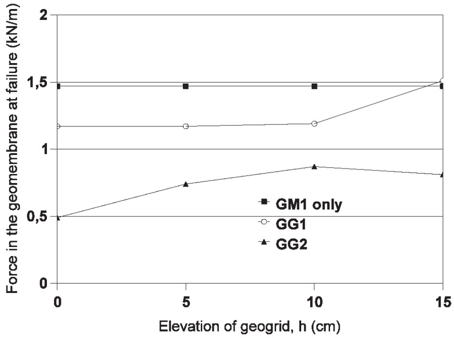

Figure 8. Force in the geomembrane at failure versus e geogrid elevation (h).

may have influenced the shear stresses transferred to the geomembrane.

3.2 *Influence of geomembrane and geogrid types*

Tests with the rough geomembrane GM2 were also carried out with and without the presence of geogrid reinforcement in the cover soil. Figure 9 shows the variation of top box displacement versus ramp inclination for tests with geogrids GG1 and GG2 and geomembranes GM1 and GM2. In these tests the geogrid elevation (h) was equal to 10cm. Failure occurred at slightly greater ramp inclinations in tests with the rough geomembrane.

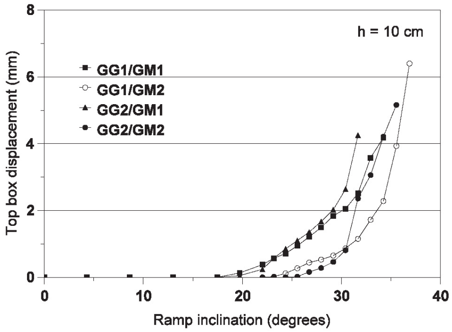

Figure 9. Top box displacement versus ramp inclination – h = 10 cm.

Figure 10 shows the variations of mobilised forces in the geomembrane versus ramp inclination. It can be noted that the presence of geogrid GG2 in the cover soil had a great effect on the reduction of the force mobilised in geomembrane GM2, similar to what was observed in tests with geomembrane GM1, although with a more significant geomembrane force reduction in the former case.

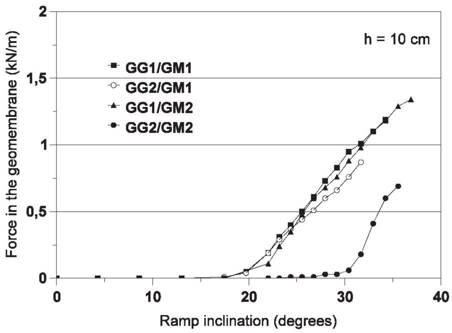

Figure 10. Force in the geomembrane versus ramp inclination – h = 10 cm.

4 CONCLUSIONS

This paper presented an experimental study on the interaction between different geosynthetics and soils in large scale ramp test. The main conclusions obtained are summarised below.

The ramp test is a useful tool for the study and evaluation of interface strength parameters under low stress levels. This is particularly interesting for the stability analysis of cover soils of works such as slopes of waste disposal areas.

The use of geogrid reinforcement in the cover soil can significantly increase the ramp inclination at failure and reduce the tensile force mobilised in the underlying geomembrane. For a given ramp inclination this fact can provide an additional safety factor against slope failure. The overall deformation of the system is also reduced with the presence of the geogrid reinforcement. The beneficial effect of the geogrid depends on its elevation with respect to the geomembrane layer.

The test results showed that the geometry and surface characteristics of the geogrids influenced the interaction mechanisms between soils and geosynthetics tested. The geogrid stiffness was an important parameter for the reduction of forces mobilised in the geomembrane.

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