Ramp tests on sand-GCLs interfaces under different moisture and surface conditions

Viana, H.N.L.
Secretariat of Water Infrastructure, Ministry of National Integration, SIH/MI, Brasilia-DF, Brazil
Palmeira, E.M.
Department of Civil Engineering, University of Brasilia,UnB, Brasília-DF, Brazil
Viana, P.M.F.
Department of Civil Engineering, University of Goias, UnUCET-GO, Anapolis-GO, Brazil

Keywords: bentonite, GCL, geomembrane, interaction, ramp test.

ABSTRACT: Geocomposite clay liners (GCL's) have been increasingly used as barriers in waste disposal areas, usually combined with geomembranes. In slopes of such areas the stability of the system must be verified in order to avoid failures mechanisms that may occur internally to the GCL or along weak interfaces in the lining system. The ramp test can be a useful tool for the study and evaluation of interface shear strength in slopes of waste disposal areas, being one of its main advantages the possibility of simulating the low stress levels on the interface expected in the field. This paper presents results of large scale ramp tests on sand-GCL interfaces. The ramp apparatus used allows tests on 2 m x 0.5 m geosynthetics specimens and the tensile loads mobilised in the geosynthetics during the tests can be measured. Two types of GCL's were tested under different conditions of ramp surface roughness simulated by different geomembrane products. The soil used in the tests was an uniform sand. Tests on the GCL's were carried out under dry conditions and after hydration. The results obtained in the ramp tests showed the importance of the surface roughness of the GCL, as well as of its structural characteristics, on the deformability of the system and maximum ramp inclinations obtained. The ramp surface roughness was also a key factor for the tensile forces mobilised in the GCL.

1 INTRODUCTION

Different types of geosynthetics can be used on the slopes of waste disposal areas, channels or reservoirs. Geomembranes, geocomposite clay liners (GCL's), geotextiles, geocomposites and geogrids can be used for different functions. These products are associated with different layers of soils on the slope. Low adherence between geosynthetics and cover soils or low internal shear resistance of GCL's can yield to failure of the lining system. Low stress levels and water flow through the cover soil are additional complicating factor for stability analysis or for the stability of the lining. Thus, it is of utmost importance to have an accurate determination of interface strength between soils and geosynthetics for that matter.

Regarding GCL's, failure can take place along the interface GCL-cover or bottom soil or internally to the GCL. Gross et al. (2002) present cases of failures of lining systems involving the use of GCL's. In general, these failures resulted in mechanical damages, impaired function of the system and financial losses motivated by need for implementation of repair works.

This paper presents a study on the stability of lining systems using a large scale ramp test apparatus with different types of interfaces involving geomembranes, GCL's and soils. Interfaces subjected to dry and moist conditions, under different stress levels were evaluated. The expansibility of GCL's, the tensile loads mobilised in the geosynthetics and the deformability of the systems tested were also investigated.

2 MATERIALS AND APPARATUS

2.1 *Equipment*

A large ramp (inclined plane) apparatus was employed in the test programme. Figure 1 shows schematically this equipment, which allows testing interfaces 2m long by 0.5m wide. Different surcharges can be applied to the cover soil to obtain the failure envelope of the interfaces. The geosynthetics layers can be anchored to the extremity of the ramp and load cells allow for the measurement of the mobilised tensile loads in the geosynthetics during the test (Fig. 1). Displacement transducers allow for the measurement of relative displacements between the box containing the soil and the ramp surface. The test was characterized by gradual increases of the inclination of the ramp with the horizontal until failure occurred. The methodology for preparing the test was equal to that employed by Palmeira et al. (2002).

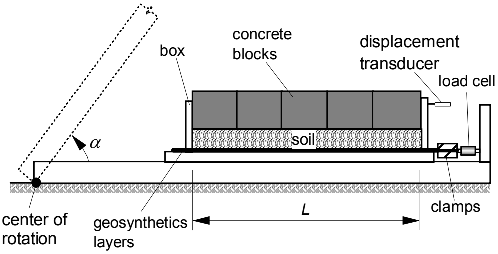

Figure 1. Ramp test equipment.

Tests on dry and hydrated interfaces were performed. Figure 2 shows the procedure used to hydrate the interface in the ramp test equipment. Basically, it consisted of submersion of the soil and geosynthetics in water plus injection of water through the gaps between the dead weights used as surcharge. The soil-GCL systems were hydrated for 48 hours before testing. During the period of hydration, displacement transducers allowed the measurement of average vertical displacements due to the expansion of the GCL. This period of hydration was considered satisfactory for the tests purposes. After the period of hydration, the water was drained and the test started. At the end of each test, the moisture content of the bentonite within the GCL was obtained.

Different conditions of roughness underneath the different GCL's were employed by using geomembranes with surface characteristics. The use of these geomembranes on the ramp surface aimed at investigating the influence of varying roughness conditions underneath the GCL layer on the test results. Thus, the configuration of the tests consisted, from top to bottom, by the soil layer, a GCL and a geomembrane (on the ramp surface).

2.2 *Cover Soil*

An uniform sand was used as cover soil in the tests. Table 1 summarises the main properties of the sand. The sand specimens were 50mm thick and were compacted by tamping to reach a relative density of 57%.

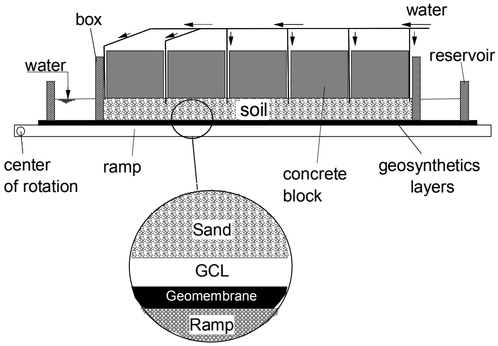

Figure 2. Hydration of the system.

Table 1 – Soil properties

Material	D_{10} (1) (mm)	D_{60} (2) (mm)	CU(3)	Gs(4)	ϕ□ (°)
Sand	0.63	1.00	1.61	2.57	37

Notes: (1) D_{10} = particle diameter for which 10% of the remaining particles are smaller than that diameter; (2) D_{60} = particle diameter for which 60% of the remaining particles are smaller than that diameter; (3) CU = coefficient of uniformity (= D_{60}/D_{10}); (4) soil particle specific density; (5) friction angle.

2.3 *Geosynthetics*

Three geomembranes underneath the GCL's for roughness purposes and two GCL's were used in the tests. Table 2 presents the main characteristics of these materials. GMS is a smooth HDPE geomembrane. GMR1 and GMR2 are rough geomembranes. The roughness of GMR1 is mainly due to sparsely distributed bumps, where the overlying material may also interact with the geomembrane by local bearing. GMR2 has a uniform rough texture similar to sandpaper. Figure 3 presents views of the surfaces of the geomembranes used in the tests.

Table 2. Geosynthetics characteristics.

Geosynthetic	Code	M_A(2) (g/m^2)	t_G(3) (mm)	T_{max}(4) (kN/m)	ε_{max}(5) (%)	J(6) (kN/m)
Geomembrane HDPE(1)	GMS	950	1.0	20/33(4)	12/700(5)	260
	GMR1	950	1.0	20/33(4)	12/700(5)	260
	GMR2	≥ 940	2.0	29/21(4)	12/700(5)	300
GCL	GCL1	5000	5.0	---	---	---
	GCL2	6000	6.0	---	---	---

Notes: (1) PP = polypropylene, HDPE = high density polyethylene, PET = polyester; (2) M_A = mass per unit area; (3) t_G = thickness; (4) T_{max} = tensile strength from wide strip tensile tests in each direction; (5) ε_{max} = yield and rupture tensile strains; (6) J = secant tensile stiffness.

The geosynthetic clay liner GCL1 is a needle-punched (not reinforced) product, consisting of a sodic bentonite in between a cover nonwoven geotextile and a bottom woven geotextile. GCL2 is a stitched (reinforced) geocomposite clay liner consisting of a calcic bentonite layer in between layers of woven geotextiles. In the latter GCL the surface of the geotextiles was roughened by a layer of sand glued by resin to the geotexile surface.

(a) GMS

(b) GMR1

(c) GMR2

Figure 3. Views of the geomembrane surfaces.

Additional information on test equipment and methodology are reported by Viana (2003), Palmeira and Viana (2003) and Viana (2007).

3 RESULTS AND DISCUSSIONS

The condition of hydration, normal stress and characteristics of the GCL's influenced significantly the expansion observed in the tests. Figure 4 shows that the expansibility of GCL1 was greater than that obtained for the GCL2, irrespective of the surcharge applied. In this figure it can be seen that GCL1 expanded from 1.8 to 4 times more than the GCL2, depending on the normal stress considered. Small variations of normal stress influenced markedly the absorption of water by the structure of the bentonite of the GCL's. This behavior was also observed by Koerner (1994) in tests performed on some GCL's under confinement hydrated with different types of liquids. This fact is extremely important because the moisture of the bentonite in the GCL is directly associated with its expansibility and permittivity.

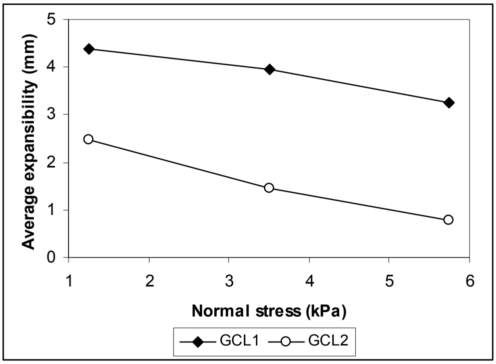

Figure 4. Average expansibility versus normal stress.

GCL2 had its expansion hampered by the stitches. In addition, the external surfaces of GCL2 are impregnated with a resin that can delay the entry of water into the product and consequently its expansion. The different chemical compositions of bentonites of the GCL's tested also resulted in different levels of expansibility. Clays with larger amount of sodium as the exchangeable cation in its mineralogical structure are considerably more plastic and expansive than the calcic clays (Santos, 1975).

Figures 5 and 6 present the box displacements and values of ramp inclinations measured (at failure) versus normal stress for dry and hydrated systems. Figure 5 shows that hydrated systems GCL1-GMS (smooth geomembrane surface) and GCL1-GMR2 presented the largest displacements (between 36-62mm). Hydration of the system prior to testing increases the system deformability. In most cases, tests on systems with rough geomembranes presented significantly less box displacements at failure. It can be noted that the hydration of the systems had little effect on the ramp inclination at failure. The larger displacements of the box containing the soil in tests on GCL1-geomembranes systems was probably associated with the internal failure of GCL1 as shown in Figure 7. This figure presents results of direct shear tests on samples of GCL1 and GCL2 with bentonite at natural moisture content and under a normal stress equal to 80 kPa. The internal failure of GCL1 was associated with very low strains (≈1.5%). However the level of stresses employed was not sufficient to promote the internal failure of GCL2. In ramp tests, for the same moisture conditions, the failure of the sand-GCL1 interface occurred with displacements ranging between 18-62mm, depending on the geomembrane considered, hydration conditions and normal stress applied. It can be noted that dry conditions yielded to stiffer responses of the interfaces. On the other hand, hydration increased the deformability of the system.

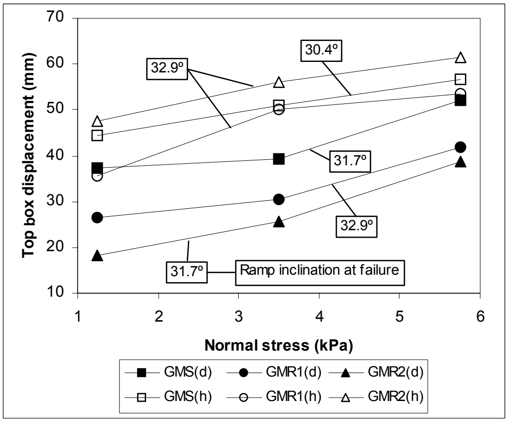

Figure 5. Top box displacement versus normal stress in tests with GCL1 on different surface conditions (geomembranes) under dry (d) and hydrated (h) conditions.

Figure 6 shows that the additional roughness of GCL2 provided by the impregnation of sand yielded to a significantly better performance than that obtained in tests with GCL1. Hydrated systems GCL2-GMR2 presented smaller displacements (between 1-19mm). Hydration affected the level of displacements and increased the ramp inclination at failure for all tests with GCL2. This was due to the deformed shape of this GCL after expansion of the bentonite, as shown in Figure 8. This deformed shape increases the contact area between soil and GCL surface and increases adherence. Greater internal and interface strengths were obtained for GCL2 because of the strength of its stitches and surface roughness.

Figures 9 and 10 present the GCL tensile forces and values of ramp inclinations measured (at failure) versus normal stress for dry and hydrated systems. Figure 9 shows that the roughness of the geomembranes did not affect significantly either the tensile forces mobilized in GCL1 or the ramp inclination at failure in tests under dry conditions. Hydration increased the tensile force in GCL1 by up to 25%, depending on normal stress considered.

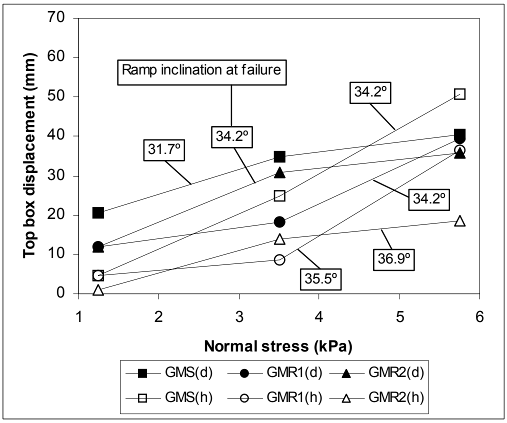

Figure 6. Top box displacement versus normal stress in tests with GCL2 on different surface conditions (geomembranes) under dry (d) and hydrated (h) conditions.

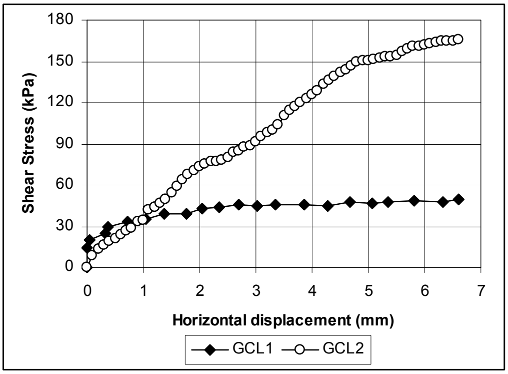

Figure 7. Direct shear tests (0.10m x 0.10m) in GCL's samples – bentonite at natural moisture and normal stress equal to 80 kPa (Viana, 2007).

Figure 10 shows that the roughness of the geomembranes on the ramp surface markedly reduced the tensile forces mobilized in GCL2. Increases on friction angles between interfaces occurred due to the greater surface roughness of GCL2. This adherence yielded significant transference of shear stresses to the ramp surface. It can be noted also that hydration did not influence significantly the tensile forces mobilized in GCL2, however, it increased the ramp inclination at failure due to the deformed shape of this GCL after hydration, as commented above (Fig. 10).

Figure 8. Deformed shape of GCL2 after bentonite expansion.

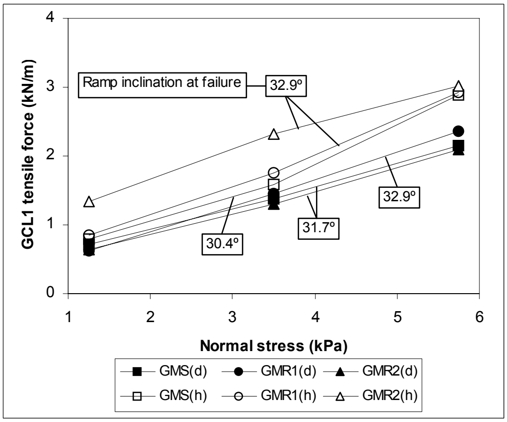

Figure 9. GCL1 tensile force versus normal stress in tests with GCL1 on different surface conditions (geomembranes) under dry (d) and hydrated (h) conditions.

As commented above, greater internal and interface strengths were obtained with the use of GCL2 because of its strong stitches and surface roughness. This is beneficial under high levels of shear stress. On the other hand, GCL1 has weak needle-punching filaments, yielding to lower internal shear strength.

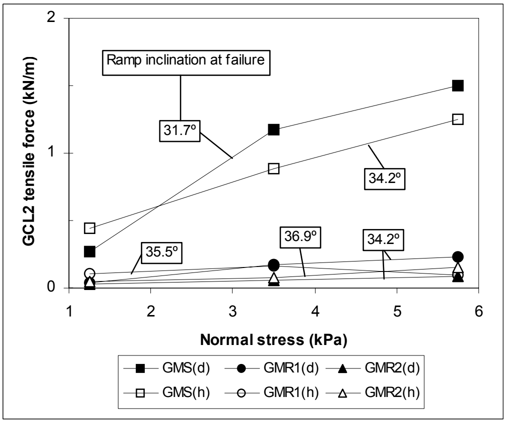

Figure 10. Tensile force versus normal stress in tests with GCL2 on different surface conditions (geomembranes) under dry (d) and hydrated (h) conditions.

5 CONCLUSIONS

This paper presented large ramp tests results on sand-GCL interfaces, with the GCL resting on surfaces of varying roughness. The main conclusions obtained are summarised below.

a) Factors such as roughness of the material underneath the GCL and GCL manufacturing process influenced the ramp inclination at failure, displacements and tensile forces observed.

b) Tests with GCL1 showed a poor performance for the hydrated system GCL1-GMS (smooth underneath surface). Hydration did not influence the tensile forces mobilised and the ramp inclination at failure. However, hydration increased the deformability of the system.

c) Tests with GCL2 showed a better performance, including under hydrated conditions. The surface roughness of GCL2 increased ramp inclination at failure.

d) The characteristics of the project and the properties of the GCL must be well known for a proper specification of the GCL product to be used. In this context, the ramp test is a useful tool for the evaluation of interface strength in lining systems.

ACKNOWLEDGEMENT

The authors are indebted to CNPq-National Council for the Scientific and Technological Development, University of Brasilia, FAP-DF-Federal District

Foundation for Research Support and Finatec/UnB for of the support to this research.

REFERENCES

Gross, B.A., Bonaparte, R. and Giroud, J.P. 2002. Waste Containment Systems: Problems and Lessons Learned. *Appendix F in Assessment and Recommendations for Optimal Performance of Waste Containment Systems*, *R. United States Environmental Protection Agency, 214 pp.*

Koerner, R.M. 1994. Designing with Geosynthetics, *Prentice-Hall Inc.4rdEd., New Jersey, 761p.*

Palmeira, E.M., Lima Jr., N.R., Mello, L.G.R. 2002. Interaction between soils and geosynthetic layers in large-scale ramp tests. *Geosynthetics International 9 (2):149–187.*

Palmeira, E.M. and Viana H.N.L. 2003. Effectiveness of geogrids as inclusions in cover soils of slopes of waste disposal areas. *Geotextiles and Geomembranes 21:317–337.*

Santos, P. S. 1975. Technology clay applied to Brazilian clays. *Edgar Blücher Ed., São Paulo.*

Viana, H.N.L. 2003. The effects of geogrids on the behaviour of cover soils of slopes of waste disposal areas. MSc.Dissertation, *Graduate Programme on Geotechnics,University of Brasilia, Brasilia, DF, Brazil, 84 p. (in Portuguese).*

Viana, H.N.L. 2007. A study on the stability and hydraulic conductivity of conventional and alternative cover systems of waste disposal areas. *PhD Thesis, Graduate Programme on Geotechnics, University of Brasilia, Brasilia, DF, Brazil, 261 p. (in Portuguese).*