Comparisons between internal shear strengths of GCLs by ramp and direct shear tests

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ABSTRACT: The internal shear strenght of GCLs can be obtainded by direct shear or ramp (inclined plane) tests. Direct shear tests can be used for normal stresses greater than 20kPa, but its results for lower normal stresses are not reliable. In this context, the ramp tests is a suitable testing technique for tests under low stress levels. To improve the understanding on the differences among results obtained in direct shear and ramp tests, a series of large scale tests using such apparatus was conducted. GCLs samples were tested under dried and hydrated conditions. The results obtained showed that significant differences among results can occur, depending on the conditions of the tests.

1 INTRODUCTION

Internal shear and interface strengths of GCLs are parameters of utmost importance for stability analyses of slopes with such materials. In barriers using such materials those strengths can be mobilised under low stress levels (σ < 50 kPa). Regarding internal shear strength, failure of the bentonite core and of the stitches of the GCL can yield to overall failure of the slope. Besides, hydration of the bentonite can cause significant reductions on GCL internal strength.The expansion of the bentonite due to moisture content increase associated to low strenght of the stitching process may compromise the performance of the system (Fox & Stark 2004, Gilbert et al. 1996, Viana & Palmeira 2008).

The ramp test and the direct shear tests have been commonly used to obtain interface and internal shear strengths of GCLs. Girard et al. (1990) used the ramp test to examine failure mechanisms along the face of Aubrac dam. Several authors have presented studies involving the use of the ramp test under different testing conditions (Gourc et al. 1996, Briançon et al. 2002, Viana & Palmeira 2008). Some of the advantages of this type of test is to provide more reliable results under low stress levels than standard direct shear test devices. Regarding the latter, ASTM D 6243 is commonly used for the evaluation of internal shear strength of GCLs, where a sample with dimensions not less than 300mm x 300mm should be employed (Fox & Stark 2004, Zornberg et al. 2005). The size of the specimen tested can have a marked effect on the result obtained, as can be seen in the results presented in Figure 1 (Viana & Palmeira 2008), which presents results of direct shear tests on dry 10cm x 10cm and 30cm x 30 cm specimens, under 100kPa normal stress. Such differences between results may be associated to heterogeneity of the GCL product, number of stitches per unit area and non repetitive sampling procedure. Shear displacements at failure vary typically between 10mm and 50 mm (Fox & Stark 2004, Viana & Palmeira 2008).

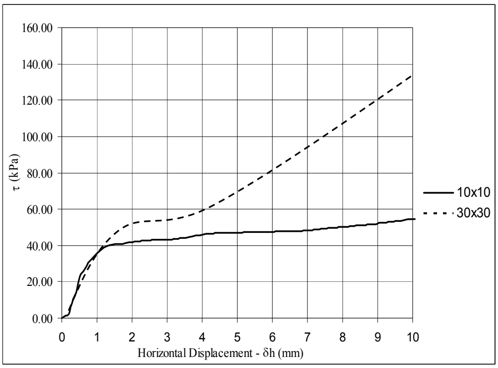


Figure 1. Shear stress – τ versus horizontal displacement - δh curves in direct shear tests on GCLs as a function of the specimen size (Viana & Palmeira 2008).

The present work aims to investigate differences in results of interface and internal shear strengths of GCLs using direct shear and ramp tests. The influence of the size of samples and of the test equipment used were assessed.

2 SCOPE OF STUDY

This paper presents results of inclined plane and direct shear tests. The tests in the inclined plane were carried out under vertical stresses of 2.5, 5.0 and 10 kPa on samples 0.6m (width) x 1m (length). The direct shear tests were performed under vertical stresses ranging form 15kPa to 400kPa on samples 0.3m x 0.3m. The tests were conducted on samples with natural moisture content and after hydration caused by submersion in water for 24h (with normal stress of 5 kPa). The tests results are presented and discussed in the following items.

3 MATERIALS AND EQUIPMENT USED

Two types of GCLs (codes GCL A and GCL B) were tested in the research programme, and their main characteristics are summarised in Table 1. Both products were manufactured with sodium bentonite.

Table 1. Basic characteristics of the GCLs used in the tests.

Characteristic – GCL	GCL A	GCL B
Bentonite (BTN)	Na	Na
Density of Bentonite (kN/m^3)	27	27
Thickness (mm)	6-7	6-7
Mass/unit area (g/m^2)	5000	4500
Natural moisture content (%)	8-14	8-14
Natural moisture content after hydration (%)	200	348
Type of bonding process	Stitch Bonded	Needle Punched

Large direct shear and ramp test devices were used in the testing program. The ramp test equipment (Fig. 2) allows testing GCL specimens 0.6m x 2.2m. The specimen can be fixed to the ramp along its entire length or have its raising end anchored to the ramp extremity. For the latter case, which was the one adopted in the present work, load cells provide the tensile forces mobilised in the specimen during the test. For the ramp tests the interface between the GCL specimen and the ramp was lubricated with double layers of plastic films and grease. Displacement transducers allowed for the measurement of the displacements of the top box used to confine the soil or the surcharge weights during the test. Figure 2 presents a view of the equipment during one of the tests.

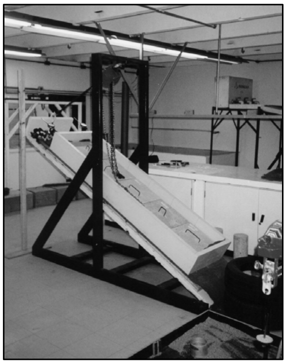


Figure 2. Ramp test equipment.

The direct shear apparatus used is a servo-controlled equipment capable of testing specimens 30 cm x 30 cm under normal stresses up to 400 kPa. Figure 2 shows a view of the apparatus. ASTM D 6243 recommendations were used in the tests carried out.

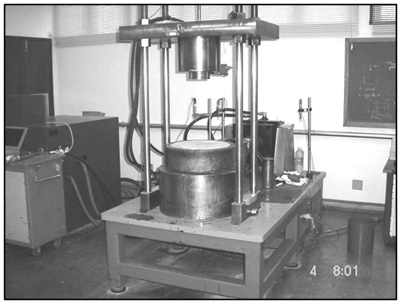
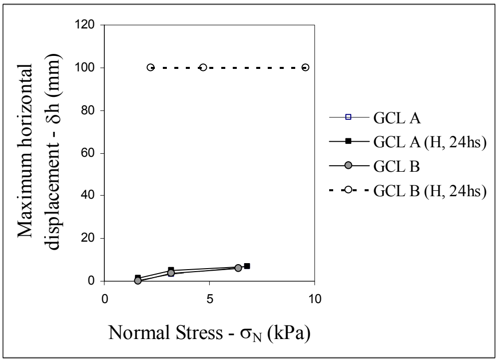


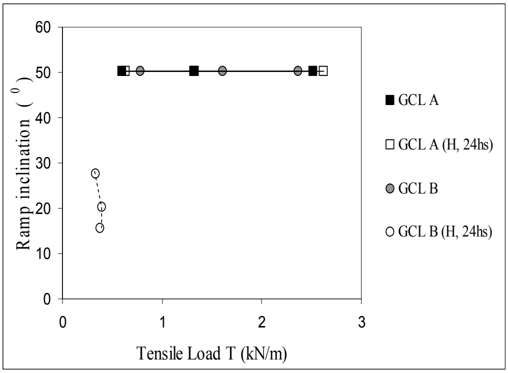
Figure 3. Direct shear test equipment.

4 RESULTS AND DISCUSSION

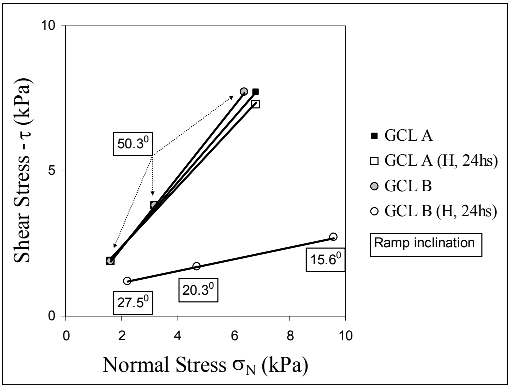
Figures 4a to 4c show results of ramp tests on dry (natural water content) and hydrated GCL specimens. It can be noted that internal shear failure did not take place up to the highest value of ramp inclination (50.3^o) reached (Fig. 4a), except for the test with the hydrated specimen of GCL B. Maximum displacements of the hydrated specimen GCL B reached 100mm for all normal stress values, whereas for the other tests the maximum displacements were below 7mm. Figure 4b shows that the highest tensile loads were also mobilised in the hydrated specimen of GCL B. Internal failure of this GCL was reached for a friction angle (ϕ_{int}) of 11.5^o, which is similar to the friction angle obtained for the hydrated bentonite (Viana H & Palmeira 2004, Viana & Palmeira 2008). For the other specimens tested (no internal failure) the mobilised friction angle is greater than 50^o.



(a)



(b)



(c)

Figure 4. Results of ramp tests with: (a) Maximum horizontal displacement versus normal stress, (b) Tensile load versus ramp inclination, and (c) Shear stress versus normal stress.

The loss of strength of the hydrated GCL B was a consequence of the failure of the fibers because of the free expansion of the bentonite during hydration prior to the test. Figure 5 shows an evidence of stitch failure in that GCL after hydration. Failure of the fibers may be minimised or avoided if the GCL is confined, because of less expansion under such conditions. However, this aspect must be well know for the GCL product, as it may cause significant reductions of its internal shear strength.

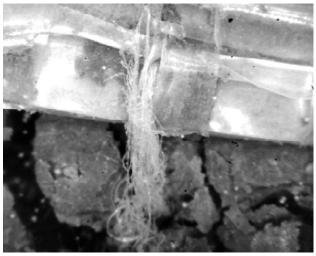


Figure 5. Fibers failure in GCL B after hydration.

Figure 6 shows a typical curve of internal strength test result obtained in the large direct shear device (GCL A with σ_N = 100 kPa). In general, a very distinct peak strength value was observed, with severe strength reduction post-peak. The internal strength parameters (adhesion and equivalent friction angle) for the dry GCL A was equal to 120 kPa and 25^o, whereas for the same GCL after hydration those values were equal to 70kPa and 27^o, showing that the equivalent friction angle was predominantly influenced by the strength of the fibers. The internal strength of the hydrated GCL B was approximately the same as that of the hydrated bentonite and similar to that obtained in the ramp test, due to the low contribution of its fibers, as most of them failed during bentonite expansion. The values of internal strength parameters obtained for normal stresses below 400 kPa were similar to those reported by Fox & Stark (2004) and Zornberg *et al.* (2005).

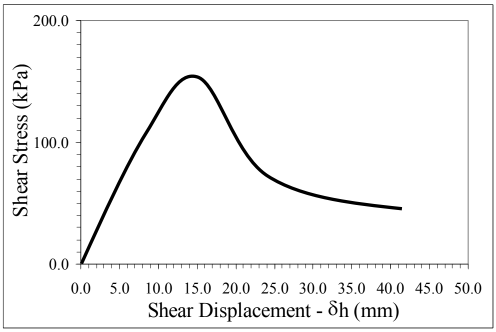


Figure 6. Typical curve shear stress x shear displacement curve obtained in large direct shear tests.

Figure 7 presents the failure envelopes obtained in the direct shear tests for GCLs A and B, as well as the mobilised envelope for a shear displacement of 7mm. This was approximately the value of displacement reached at maximum inclination in the ramp tests. For such conditions the adhesion and equivalent friction angle obtained in the direct shear tests were 27kPa and 32° for GCL A, and 22 kPa and 28° for GCL B. These results are significantly different from those obtained in the ramp tests, mainly because of scale effects (size of specimen tested) and type of deformation mechanism imposed to the specimen in each test.

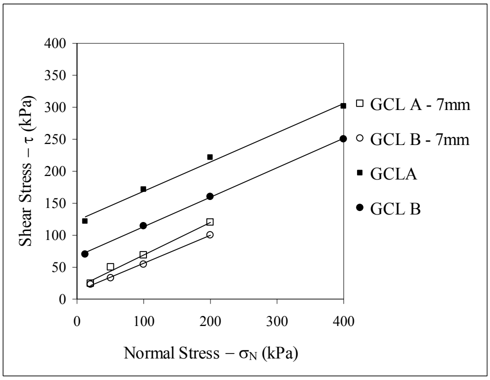


Figure 7. Failure envelopes obtained in the direct shear tests for GCLs A and B and mobilised envelope for a shear displacement of 7mm.

The results presented above show that the shear strength behaviour and values obtained in direct shear and ramp tests are significantly different. The internal shear strength of the GCL is fundamentally dependent on the stitching or needle-punching strength, with little contribution from the shear strength of the bentonite. In the ramp test the mobilised shear stresses were not sufficient to cause failure of the dry GCLs A and B nor of the hydrated GCL A. In this case failure must be associated to allowable displacements that would guarantee satisfactory operational conditions of the barrier. In this case, the ramp test is more realistic, bearing in mind the typical geometrical and stress conditions found in the field.

5 CONCLUSIONS

This paper presented results of GCL internal shear strength using direct shear and ramp tests. The main conclusions are summarised below.

Internal failure of the GCLs tested in ramp tests was observed only for GCL B under hydrated conditions. This was caused by tensile failure of the fibers elements during expansion of the bentonite due to hydration prior to the test. For the other specimens or conditions no internal failures were observed for ramp inclinations up to 50.3°.

The internal strenght of the hydrated GCL B was approximately that of the hydrated bentonite alone, because of the low contribution of the failed fibers.

The values of mobilised internal strength parameters obtained in direct shear and in ramp tests can be significantly different, even if those parameters are defined for allowable displacements in cases where no failure may be observed. This differences were due to different testing conditions (specimen size, for instance) and different conditions of mobilisation of deformations in the specimens. In this context, the ramp test, particularly large scale ones, may simulate more accurately the condition expected in the field and provide more reliable parameters for design.

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