INTERNAL SHEAR STRENGTH AND SWELLING CHARACTERISTICS OF A GCL

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SUMMARY: A certain type of GCL, used in this research, consists of needle-punched woven and non-woven geotextiles with a natural sodium bentonite content. Swell tests on the GCL, subjected to various compressive normal stresses, were carried out in a conventional consolidometer device and internal shear strength tests were undertaken in a modified 100 mm x 100 mm direct shear device. In this paper, the results of the swelling tests are presented and the internal shear strength of the GCL at various stages of swelling (hydration) is investigated.

1. INTRODUCTION

The use of lining systems in relatively steep embankments requires careful assessment of both the internal shear strength and the interface friction between GCL and contact materials. Two kinds of GCLs, unreinforced and reinforced, are in use. Unreinforced GCLs are somewhat problematic because of their potential for hydration and the corresponding loss in shear strength of the bentonite. According to von Maubeuge and Eberle (1998), the peak friction angle of unreinforced GCLs is as low as 8 degrees. GCLs are often reinforced by needle punching synthetic fibers through the composite. Fox et al. (1998) showed that unreinforced GCLs have lower internal shear strengths than needle punched GCLs. This paper describes a laboratory investigation comprising swelling pressure tests, swell tests and internal shear strength tests at various stages of hydration. The internal shear strength of a certain type of needle punched GCL at various degrees of swelling (hydration) of the bentonite will be discussed.

Swelling pressure tests and swell tests were performed in the conventional consolidometer device in which the GCL specimens were compressed for two hours. Thereafter de-aired water was added and the swelling monitored. Three different normal compressive stresses (50 kPa, 100 kPa and 150 kPa) were applied (similar to stress levels in landfill conditions of moderate height) providing information about the rate of hydration and swelling of the GCL. Similar tests known as constant stress swell (CSS) tests were performed by Lake and Rowe (2000) to study the swelling characteristics of needle punched, thermally treated GCLs. Based on their observation, the effect of thermal treatment on the swell measure of GCLs is significant at low normal stresses (up to 6 kPa) but is overshadowed by the normal stresses as the stress increases. In general, there was not much difference in the swelling behaviour of the GCLs examined at high stresses. The effect of hydration and swelling on the internal shear strength of GCLs has not been researched.
Internal GCL shear strength is generally obtained from direct shear tests in the laboratory and is dependent on many variables including the product type, hydration time, consolidation time, shear rate, shear displacement, normal stress, and drainage conditions during hydration and shear (Qian et. al, 2002). In this study, the internal shear tests were conducted in accordance with procedures described in the respective standards to evaluate the peak and residual shear strength of the GCL. However, a standard 100mm x 100mm direct shear device was used and modified to accommodate the GCL specimens and not a 300mm x 300mm device as recommended in ASTM D6243-98.

2. TEST DESCRIPTION

2.1 Materials and Test Apparatus

The material used for the tests was a needled-punched GCL, which consisted of sodium bentonite sandwiched between woven and non-woven geotextiles. The averaged measured thickness of the GCL was 6.9 mm and the mass per unit area was approximately 4400 g/m². The bentonite had an average specific gravity of 2.667 and a natural (in the laboratory) moisture content of 10.5 percent.

To obtain swelling pressure and swell at various normal pressures, the tests were carried out in conventional consolidometer devices of 75 mm internal diameter. A procedure suggested by Head (1987) for the measurement of swelling pressure was applied. For swell at various normal pressures, the tests were performed in general conformance with ASTM D2435-90, “Standard Test Method for One-Dimensional Consolidation Properties of Soils”.

For the internal shear strength tests, a standard direct shear box device having a shear area of 100mm x 100mm was modified to accommodate the GCL. Internal shear testing was conducted in accordance with ASTM D6243-98, “Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by Direct Shear Method” to evaluate the peak and residual internal shear strength. The maximum displacement of the device was 17 mm. Pictures of a GCL prior to internal shear strength tests are shown in Plate 1. The non-woven (cover) geotextile was fixed to the upper (stationary) shear frame while the woven (carrier) geotextile was attached to the lower (moving) shear base. Special adaptations were mounted to ensure that the geotextiles were kept in place on the shear base during shear even after days of soaking.
2.2 Testing Programme

2.2.1 Measurement of Swelling Pressure

GCL specimens for both swelling pressure tests and swell tests were cut as precise as possible to be accommodated in the mould. The specimens were weighed to check the quantity of bentonite content. The edges of the specimens were wetted carefully to keep the bentonite in place.

To start the swelling pressure investigation, de-aired water was applied once the specimen was placed appropriately in the consolidation cell. As soon as swelling was indicated, a small weight was added to the hanger to achieve equilibrium and to return the dial gauge indicator back to zero. Once swelling continued, additional weights were applied to restrict the deformations and to keep the gauge as closely as possible to zero. If the specimen was left overnight, sufficient weights were placed on the hanger to ensure that excessive swelling did not occur while it was unattended. The pressure required to maintain the specimen’s original thickness (height) with time is known as the swelling pressure. The tests were carried out for a period of up to 110 days to establish a swelling pressure. A swelling pressure versus time diagram is shown in Figure 1 of the most successful test.

2.2.2 Swell Tests

Swell tests, also known as constant stress swell (CSS) tests, were performed to investigate the swelling characteristics of the GCL. Three normal compressive stresses of 50 kPa, 100 kPa and 150 kPa were applied and held for 2 hours. At the end of the initial compression stage, de-aired water was introduced to the sample and the height of the samples monitored. These tests provided information about the rate of hydration and, thus, the swell of the GCL. The final swelling height was established after 110 days. The swell versus time relationships of three tests are shown in Figure 2.

2.2.3 Internal Shear Strength Tests

To investigate the internal shear strength of the GCL, a standard direct shear device was used and the GCL arranged in such a way that failure was forced to occur within the bentonite layer. The tests were carried out using different normal stresses i.e. 25 kPa, 50 kPa, 75 kPa, 100 kPa and 125 kPa at a shearing rate of 0.77 mm/min. Based on the information provided by the swell test curves for various normal stresses (as shown in Figure 2), series of internal shear strength tests were undertaken of “dry” and “hydrated” GCLs. The GCL with natural moisture content i.e. 10 % was considered “dry” while the GCL at various stages of hydration i.e. 1 day and 3 days of soaking in de-aired water was considered “hydrated”.

All GCL samples were cut to exact dimensions and the weight was checked to ensure consistency in the mass of the bentonite content. The preparation of GCL samples was carried out as careful as possible to limit the loss of bentonite at the edges. Once the sample was ready and placed in the direct shear frame, a normal stress was applied and held for 2 hours to allow for the GCL to compress as done in the swell tests. At the end of the compression phase, the sample was sheared. In the case of the “hydrated” GCLs, de-aired water was introduced prior to shearing. The relationships between shear stress and displacement for “dry” and “hydrated” GCLs are shown in Figure 4, 6 and 8 while the observed maximum shear stresses related to normal stresses for “dry” and “hydrated” GCLs are shown in Figure 5, 7 and 9.
3. RESULTS AND ANALYSIS

3.1 Swelling Pressure Tests

As shown in Figure 1, a dramatic increase in swelling pressure was observed in the first two days after the GCL specimen was submerged in de-aired water. Thereafter, it took approximately 25 days to approach the final swelling pressure of 110 kPa while continuously adding small weights to balance swelling pressure and loading. Thereafter no significant increase of pressure was observed. The test was terminated after 110 days.

![Swelling pressure versus time relationship of a selected swell test](image)

3.2 Swell Tests

In Figure 2 the swell test curves at various normal stresses are shown. The highest swell of the specimens subjected to 50 kPa, 100 kPa and 150 kPa normal stresses were 2.132 mm, 1.254 mm and 1.220 mm, respectively. The measure of maximum swell and normal pressure is plotted in Figure 3. It appears that the final swell decreases with an increase in normal stress. These results agree well with the results obtained by Lake and Rowe (2000). It took approximately 24 days to complete the swelling process in all GCL specimens.

In Table 1, the percentages of swell at various days of hydration and normal stresses are listed. For a hydration period of 1 day, the swell was recorded at 0.430 mm (20.2% of maximum swell), 0.362 mm (28.9%) and 0.328 mm (26.9%) for the respective normal stresses. After 3 days of hydration, the swell was recorded at 1.762 mm (82.7% of maximum swell), 1.102 mm (87.9%) and 0.946 mm (77.5%). It can be said that for 1 day of hydration, the average swell for the GCL is 25.3 % while for 3 days of hydration, the average swell is 82.7 %.

It was decided that the internal shear strength should be investigated for those two significant hydration stages. The period required for 100% swell was ruled out due to the onset of excessive corrosion on parts of the shear device.
Figure 2  Swell test curves at various normal stresses

Figure 3  Relationship between maximum swell and normal stress

Table 1  Percentage of swell at various days of hydration and normal stress

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3.3 Internal Shear Strength Tests

In Figure 4, the results of the internal shear tests are shown in terms of shear stress versus displacement of “dry” GCLs. For a normal stress below 75 kPa, the shear stress increases rapidly at small displacements. After reaching a shear stress of about 60 kPa, which is between 5 mm to 10 mm of displacement, the rate of increase levels off with continued displacement. A peak value is not noticeable. However, for normal stress in the order of 100 kPa and above, peak shear stresses are observed after about 10 mm displacement which drops off with increasing displacement. A similar pattern – although the shear stresses are significantly lower - is observed for GCLs subjected to a 1 day and a 3 day hydration period, as shown in Figure 6 and 8.
Figure 4  Relationship between shear stress and displacement of “dry” GCLs

Figure 5  Maximum shear stress - normal stress diagram of “dry” GCLs

Figure 6  Relationship between shear stress and displacement of GCLs after 1 day of hydration
Figure 5 shows the internal shear strength of “dry” GCLs in a maximum shear stress-normal stress diagram. It was calculated that the angle of friction and ‘cohesion’ (or rather adhesion) is 18.2 degrees and 45 kPa, respectively. Figure 7 and 9 show the internal shear strength of the GCLs after 1 day and 3 days of hydration. The angle of friction and adhesion are 18 degrees and 30 kPa for 1 day of hydration and 18 degrees and 24 kPa for 3 days of hydration.

![Figure 7](image7.jpg)  
**Figure 7**  Maximum shear stress - normal stress diagram of GCLs after 1 day of hydration

![Figure 8](image8.jpg)  
**Figure 8**  Relationship between shear stress and displacement of GCLs after 3 days of hydration

In summary, all the maximum shear stress versus normal stress results of the internal shear tests of the GCLs at various stages of hydration are shown in Figure 10. It appears that the angles of friction for the experienced test periods of hydration are similar; that is approximately 18 degrees.
In contrast, the values of adhesion reduce, initially rapidly, as the time of hydration (swelling) increases. Dry GCLs develop the highest adhesion values (in the order of 45 kPa). The longer the process of hydration progresses, the more water can penetrate the bentonite mineral structure and the less resistive the GCLs become to internal shear. The adhesion drops to 30 kPa in the case of the 1 day hydration tests i.e. 24 kPa (for 3 days hydration).

Thus, it is believed that the needle-punched fibers that hold the bentonite and the two carrier geotextiles together provide the 'frictional' internal strength. Once these fibers are fully stretched to the point that they pull out or break, their contribution to the internal strength of the GCL decreases. Only limited pull-out and breakage of the fibres was observed (most likely due to the displacement limitation of the shear device) in the described tests and failure occurred within the bentonite core.
There was no clear indication of the effect of the swelling pressure (according Figure 1 in the order of 80 kPa) which developed during the hydration periods of 1 and 3 days in terms of the internal angle of friction.

4. CONCLUSIONS

The selected type of GCL develops a swelling pressure of 110 kPa once wetted and it takes about 25 days to reach the final measure of swell. The results from the swell tests of the GCLs subjected to normal stresses of 50 kPa, 100 kPa and 150 kPa show that the measure of swell increases as the normal stress decreases. It took about 24 days to reach the final swelling height.

Based on these observations, internal shear strength tests were carried out at three different conditions which were classified as "dry" (i.e. natural moisture content), 1 day of hydration (corresponding to 25.3% of maximum swell) and 3 days of hydration (82.7% of swell). It is observed that as the hydration time increases, the internal shear strength of the GCL decreases. The angle of friction is found to be 18 degrees and believed to be similar for all conditions while the value of adhesion reduces as the hydration time increases.

It should be noted that these tests represent only the start of a wider investigation into the shear behaviour of GCLs and these results are trend indicators which need to be explored more fully.

REFERENCES


