IN-PLANE FLOW CAPACITY TESTING OF GEOCOMPOSITE DRAINS USING SOFT PLATENS AND HIGH STRESSES

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Abstract: EN12958 is a test method for in-plane flow capacity of geocomposite drains. The standard uses soft platens and has an upper confining pressure limit of 200kPa. For many deep applications test pressures up to 1000kPa are required. This paper describes how testing at these pressures can be performed using the EN12958 test procedure with modified apparatus and soft platens that are characterised up to 1000kPa. Results of in-plane flow capacity tests on both cuspated geocomposite drains and geonet composite drains at 1000kPa are presented.

Keywords: cuspated drainage sheet, drainage, flow capacity, geocomposite drainage, materials, hydraulic properties, geonet.

INTRODUCTION

Geocomposite drains consist of a polymer core bonded to a geotextile on one or both sides of the core. There are many forms of polymer core, the most common being a geonet (bi-planar or tri-planar), a cuspate (single or double) and a random fibre (plain or zig-zag). The most common polymer for the core is HDPE (High Density Polyethylene) and PP (Polypropylene), HIPS (high impact polystyrene) or PA (Nylon) are also used.

Table 1. Forms of Geocomposite.

			In-Plane Flow	
Form	**Style**	**Diagrammatic Form**	**MD(Length)**	**CMD (Width)**
Geonet	Bi-planar	XXXXX	√ √	√
	Tri-planar		√√ √ √	X
Cuspate	Single		√√ √ √	√√ √ √
	Double		√√ √	√√ √
Random Fibre	Plain		√√	√√
	Tight Zig-Zag		√√ √	√√
	Open Zig-Zag		√√	√

The three main functions of the core are to create a good in-plane flow path, resist compressive forces and to provide good support to the geotextile to prevent excessive intrusion into the core. These functions are in opposition and therefore the theoretical ideal of perfect flow and perfect support is rarely, if ever, achieved. Each producer makes a compromise but some are better than others and excessive geotextile intrusion significantly reduces in-plane flow on some products.

The tensile modulus of the geotextile also has an influencing factor on the in-plane flow. The geotextile requires some ability to stretch so that the geocomposite will conform to the contours on site but if the geotextile has a low initial modulus then excessive intrusion of the geotextile into the voids of the polymer core will occur.

Boundary Conditions

The boundary conditions either side of the geocomposite also have a significant effect on the in-plane flow, (Zhao *et al* 1999). A hard boundary in contact with the geocomposite will result in less geotextile intrusion than a soft boundary such as soil or granular fill (Figure 1). For example, if the geocomposite is used between two HDPE geomembranes such as in a landfill leak detection application, then these relatively stiff boundaries give minimal intrusion into the core. More usually, however, the geocomposite is backfilled with a soft soil or granular material and such boundary conditions act on the geotextile surface of the geocomposite, causing the geotextile to intrude into the core and reduce the in-plane flow. The higher the confining pressure applied to the geocomposite, the more significant the intrusion and hence the greater the reduction of the in-plane flow capacity. EN ISO 12958 utilises a soft foam rubber to simulate a soil/granular stone boundary.

The core itself will also compress in response to the applied confining pressure on the geocomposite. For most (not all) geocomposite products, the loss of in-plane flow at the working pressure of the core due to core compression is small in comparison with the loss of in-plane flow due to geotextile intrusion.

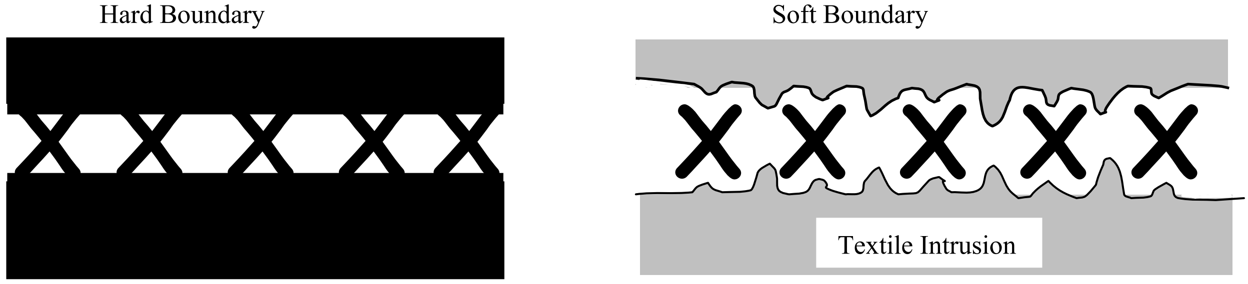

Figure 1. Geotextile intrusion into the core under different boundary conditions.

Compressive Strength

The short term compressive strength of a geocomposite drain is not as simple to determine as it might at first appear. ASTM D1621 is often used but this test is not specifically intended for geocomposite drains. (or anything less than 25mm thick). ASTM D1621 defines the compressive strength as that which causes 10% compressive strain, however, producers' datasheets often give the ultimate strength – this could be the peak compressive strength before collapse, the yield strength or indeed the ultimate compression of solid plastic. The short term compressive strength stated on datasheets is not a reliable indicator of drainage performance. The compressive characteristics are extremely product specific and even the draft ISO 25619-2 fails to anticipate the behaviour of all types of geocomposite drain. The solution, however, is to ignore the short term compressive strength completely. Far better to look at the long term compressive performance and hence to conduct an accelerated creep test at the intended design working pressure to ensure that the creep compression at that pressure is realistic. Then conduct the in-plane flow test at that same design working pressure and apply the creep reduction factor to the resulting in-plane flow to obtain the allowable long term design flow.

Creep

The testing performed for this paper was of short duration and consequently the confining pressures applied to the geocomposite produced only the short term in-plane flow performance. The effect of long term creep on the in-plane flow capacity of geocomposite drains depends on the magnitude of the applied pressure relative to the peak short term compressive strength. Generally, the working pressure should be no more than 10-20% of the short term peak compressive strength to minimise long term creep. In which case, the loss of in-plane flow performance due to creep is insignificant compared to the effect of the selection of the appropriate boundary conditions for the in-plane flow measurement itself. Rather than generalise, however, it is now possible to rapidly assess the effect of long term creep at the design pressure by a SIM (Stepped Isothermal Method) test (Greenwood et al 2008) and use this to apply an appropriate reduction factor RFcr to the tested short term in-plane flow. For 100 year design life at the design working pressure, a reduction factor of 1.2 would be acceptable, meaning that the geocomposite retains approx 80% of its short term flow performance.

In-Plane Flow

It has become common practise to state the short-term in-plane flow of the geocomposite in the machine direction (MD) because the producer's instructions indicate the direction of laying. Most geocomposites, however, have markedly lower in-plane flow in the cross machine direction (CMD). Cupsate geocomposites are the exception. Geocomposites are designed for in-plane flow in many different applications and the confining pressure in use rarely exceeds 200kPa. There are some applications for geocomposites drains, however, where confining pressures up to 1000kPa can be encountered. For example, when a geocomposite is used for deep landfill basal and side slope drainage or large reinforced earth basal drainage.

Often the in-plane flow is measured by tests in accordance with EN ISO 12958 or ASTM D4716. There are subtle differences but basically these two test methods use similar apparatus. The major distinction is that EN ISO 12958 asks for the use of soft foam as the preferred boundary condition (with hard platens as an option) whereas ASTM D4716 is a hard platen test with the option to use soft foam.

The EN ISO 12958 test method for In-plane Flow of Geocomposites provides for a range of confining pressures from 20 to 200kPa. EN ISO 12958 indicates the use of a closed cell soft foam (Neoprene) to simulate the typical soft soil or granular material backfill upon the geocomposite. Zhao *et al* (1999) found good correlation between closed cell foam and granular backfill in terms of in-plane flow reduction due to geotextile intrusion. For soft soil backfill, however, they found that the foam under estimated the magnitude of the in-plane flow reduction. This paper sets out to extend the scope of EN ISO 12958 to higher confining pressures up to 1000kPa.

ASTM D4716 test method for In-Plane Flow has an option to use closed cell foam but the primary test is based on HARD steel boundary plates. This gives the ultimate possible in-plane flow of the geocomposite. For design, a Reduction Factor RF_{IN} is applied to allow for possible geotextile intrusion into the core and consequent reduction of the in-plane flow.

$$q_{Allow} = \frac{q_{ult}}{RF_{IN}}$$

Where q_{allow} is the allowable flow, q_{ult} is the tested flow on hard platens at 1.5 x working pressure, and RF_{IN} is the reduction factor for geotextile intrusion.

The problem is in finding a suitable value for the reduction factor for geotetile intrusion. Koerner gives possible values of RF_{IN} of 1-2 but this is not nearly enough for some geocomposites. Geotextile intrusion is product specific and can be very significant. It has been shown (Zhao *et al* 1999) that some bi-planar geonets suffer a loss of 70% to 80% of their hard platen in-plane flow value when tested to soft soil boundary conditions. ie a reduction factor of 5.

Testing to EN ISO 12958 or ASTM D4716 with closed cell foam (SOFT) is easy, reliable and a very practical way to simulate site conditions. It eliminates the need for a RF_{IN} Reduction Factor for geotextile intrusion and allows direct performance measurements of the geocomposite, ensuring realistic short-term flows are obtained. In-plane flow tests with actual site specific soils as the boundary are possible but difficult to perform.

METHOD

A representative roll of each of a bi-planar geonet and two single cuspate geocomposites was obtained. The published datasheet values are shown in the table below. Each product is from a producer of European origin.

Table 2. Published Datasheet Information

					Mean Short Term. (MD) In-Plane Flow (l/m/sec)		
Type of Geocomposite	**Crush (kPa) Resistance ASTM D1621**	**Thickness (mm) Mass (g/m2)**	**Test Standard**	**Stated Boundary Conditions**	**Confining Pressure (kPa)**	**HG 1.0**	**HG 0.1**
Bi-planar Geonet XXXXX	> 1200	6.8 980	EN ISO 12958	HARD (in notes)	20 50 100 200 500	1.50 1.23 - 0.91 0.40	0.38 0.31 - 0.22 0.10
Single Cuspate 	N/A	6.2 875	EN ISO 12958	SOFT	20 50 100 200 500	1.55 - 1.30 1.05 0.52	0.45 - 0.36 0.27 0.11
Single Cuspate (Heavy Duty) 	N/A	20* 3750*	EN ISO 12958	SOFT	20 50 100 200 500	- - 2.20 1.98 1.76	- - 0.60 0.54 0.45

* Geocomposite includes protector geotextile, net thickness 7.1mm and mass 1700g/m^2.

Test Conditions

The high confining pressures are most likely to occur in applications where the geocomposite is at the base of massive layer of fill as previously stated. In such applications, the geocomposite is most likely to be laid at a shallow gradient of 3%. EN ISO 12958 indicates tests to be conducted at hydraulic gradients of 0.1 and 1 but it is well known that the flow in geocomposite drains is not strictly laminar and therefore in-plane flow is not linearly proportional to Hydraulic gradient (Figure 2). Therefore transmissivity (m^2/s) is of meaningless value for geocomposites and best practise is to conduct flow tests at hydraulic gradients as close as possible to the applicable site conditions.

The flow tests were therefore conducted at a hydraulic gradient of 3% so that the results are more directly applicable to the most likely site conditions. The values of in-plane flow are expressed as l/m/sec which means the flow in litres per metre width of geocomposite per second.

It is customary to perform laboratory tests at standard conditions which for EN ISO 12958 means water at 20^{o}C. It is acknowledged that ground water is rarely at 20^{o}C and that water at 10^{o}C is significantly more viscous than at 20^{o}C. This leads to a reduction of the in-plane flow that will be achieved on site compared to the values obtained in the laboratory. This discrepancy could be taken into account in designs by a further reduction factor RF_{VT} for viscosity correction of the water. A reduction factor of 1.2 would, for example, mean that the geocomposite achieves approx 80% of its laboratory tested flow performance.

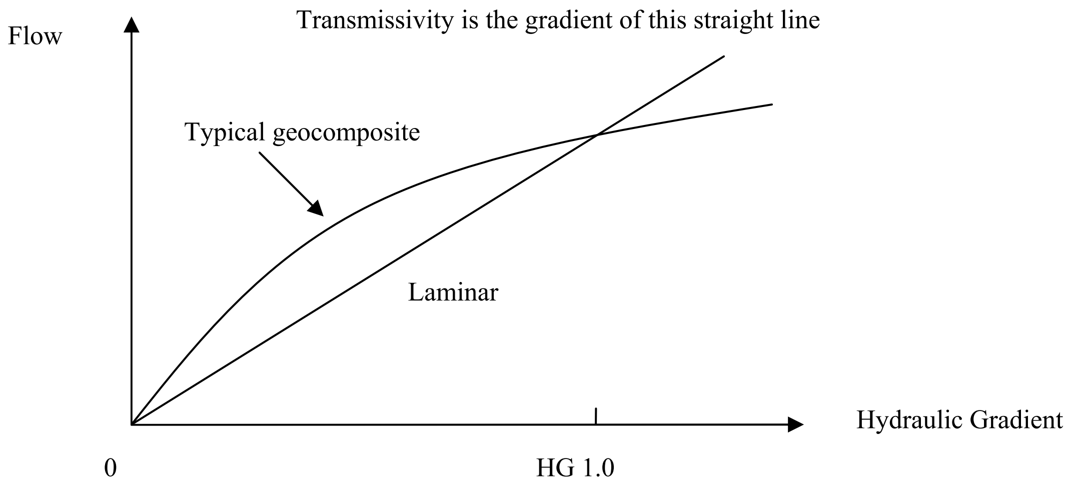

Figure 2. In-Plane Flow verses Hydraulic Gradient

Closed Cell Foam Rubber

The closed cell foam rubber otherwise called SOFT boundary conditions simulates the geotextile intrusion into the core due to a granular backfill. The characteristics of the foam are defined in EN ISO 12958 by a chart, reproduced in Figure 3.

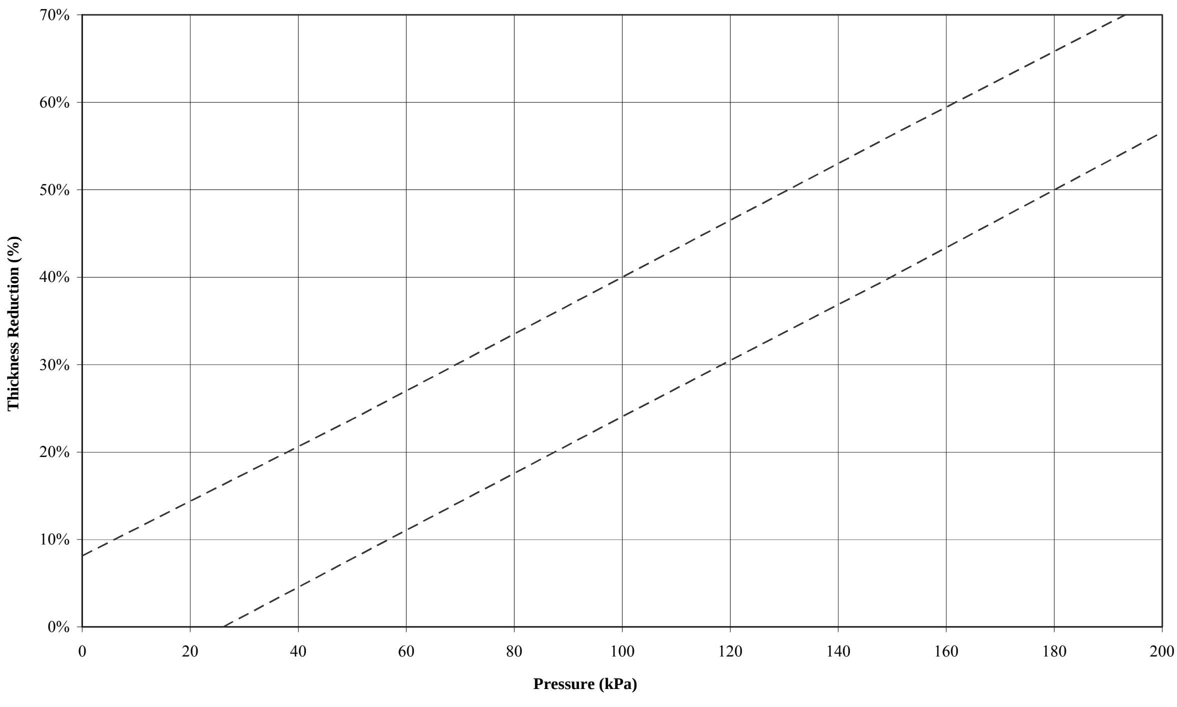

Figure 3. Closed Cell Soft Foam Rubber Characteristics EN ISO 12958

The thickness of the foam is selected relative to the thickness of the geocomposite. For the geocomposites tested, which all had cores less than 10mm thick, the foam rubber used was 10mm thick when uncompressed.

EN ISO 12958 characterises the foam rubber to a maximum of 200kPa, confining pressure. This is equivalent to approximately 10m of soil or 18m of landfill waste. For deeper applications such as landfill basal leachate collection layers, the confining pressure can reach 1000kPa. A compression test was conducted on the foam rubber using a Testometric in compression mode at 10 mm/min recording both the pressure and deflection until 1000kPa. The graphical output obtained on a 10mm thick foam rubber is indicated in Figure 4.

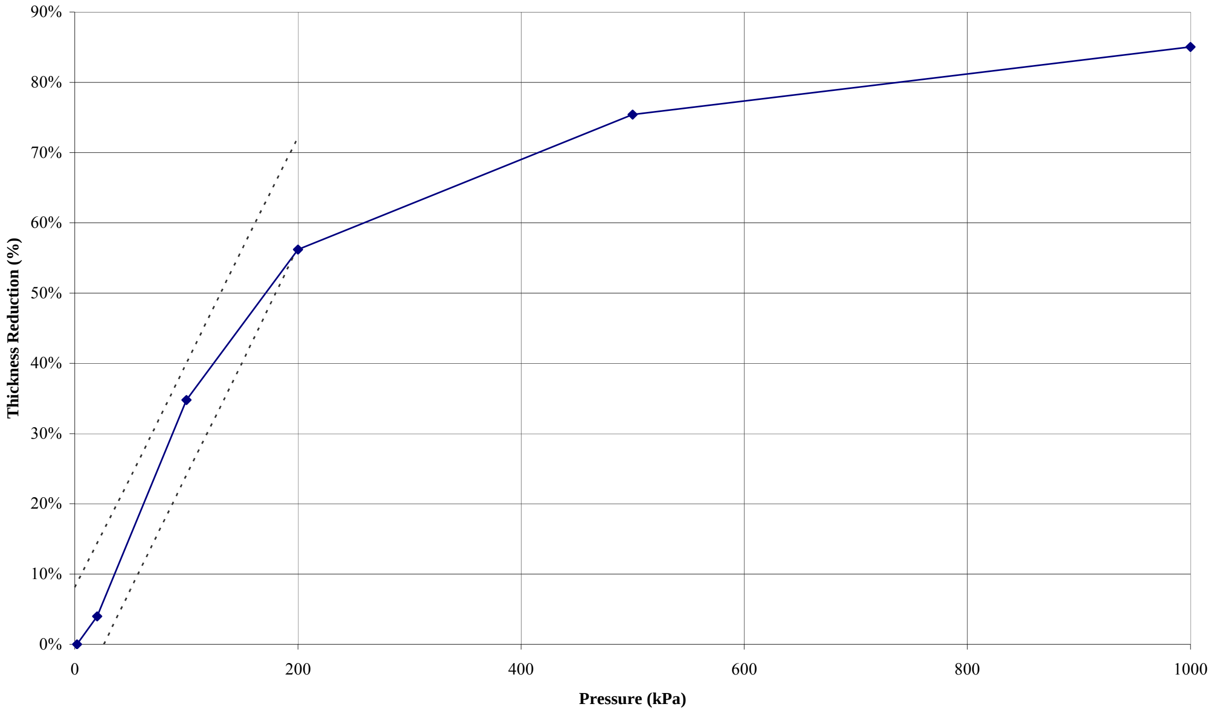

Figure 4. 10mm Foam Rubber Compression to 1000kPa.

A similar test was also conducted on a 4000 gsm non-woven needle punched geotextile and the graphical output is presented in Figure 5. The 4000 gsm geotextile is seen to be less compressible than the foam rubber. Therefore the geotextile is harder than the soft foam rubber.

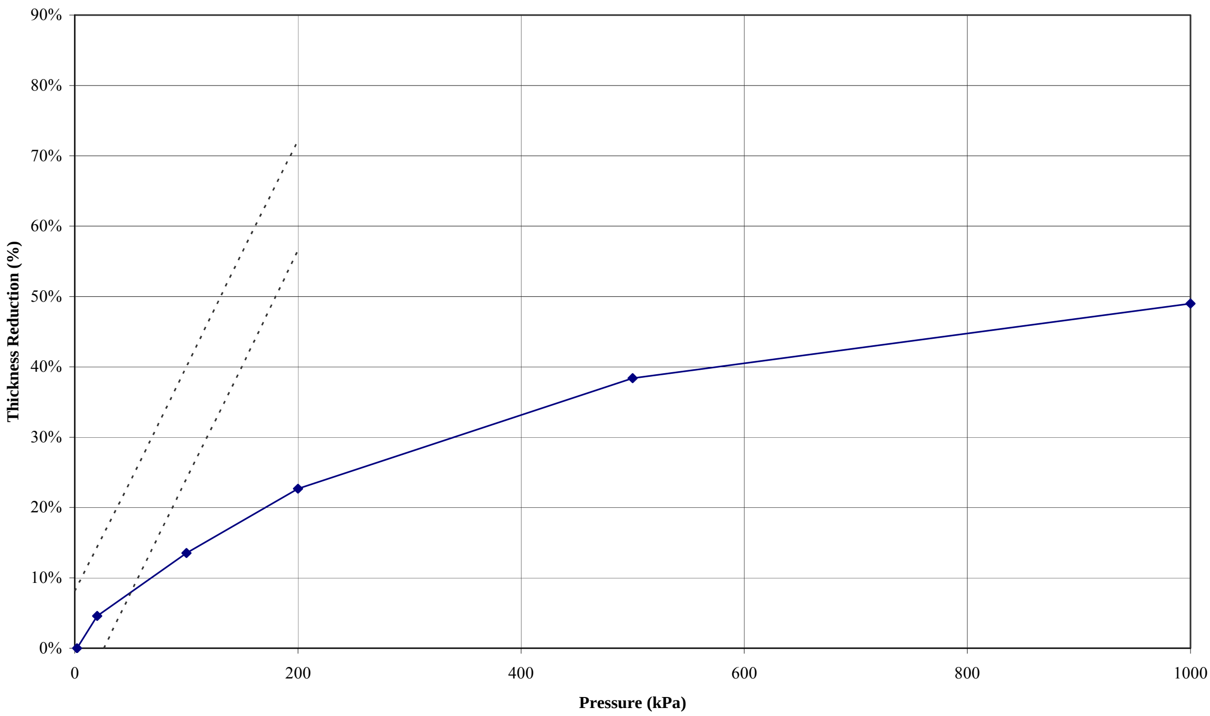

Figure 5. 4000 gsm non-woven needle punched geotextile compression to 1000kPa

The soft foam becomes noticeably stiffer after 200kPa. This is not dissimilar to a typical granular or soil backfill. Having characterised the foam rubber and geotextile, each was used in the short term in-plane flow test and two situations were simulated.

Landfill Basal Leachate Drain

The base of a landfill consists of a 1 metre compacted clay barrier, a 2mm HDPE geomembrane barrier, a 4000gsm thick protection textile, a geocomposite drainage layer, a reduced thickness of 16/20mm gravel and then the waste to a depth of 80m. To simulate this in the flow test the geocomposite drain was placed onto the 4000gsm non-woven needle punched protection geotextile and the 10mm foam rubber was placed onto the geocomposite drain. A hydraulic gradient of 3% was maintained and the confining pressure increased incrementally at steps of 20, 100, 200, 500, 1000kPa over a 60 minute time period.

Reinforced Earth Base Drain

The base of a reinforced earth wall consists of a 300mm thick granular filter stone placed onto a filter geotextile on the soil formation and construction of reinforced granular fill up to a height of 50 metres. To simulate this in the flow test, the geocomposite drain was placed on a layer of 10mm foam rubber and a further layer of 10mm foam rubber was placed onto the geocomposite drain. A hydraulic gradient of 3% was maintained and confining pressure increased incrementally at steps of 20, 100, 200, 500, 1000kPa over a 60 minute time period.

RESULTS

The in-plane flow values obtained from each test using the methodology of EN ISO 12958 with a 10mm foam rubber and 4000 gsm non-woven needle punched geotextile characterised to 1000kPa are shown in Table 3 and Figure 6.

Table 3. Short-term in-plane flow in machine direction

		MD Short term In-plane Flow at HG3% (l/m/s)				
		Confining pressure (kPa)				
Form	**Tested Boundary Conditions**	**20**	**100**	**200**	**500**	**1000**
Bi-planar Geonet XXXXX	SOFT + SOFT	0.064	0.022	0.0089	0.00046	0.000075*
	SOFT + TEXTILE	0.063	0.018	0.0080	0.0030	0.00086*
Single Cuspate 	SOFT + SOFT	0.19	0.15	0.12	0.08†	0.0027
Single Cuspate Heavy Duty 	SOFT + TEXTILE	0.23	0.19	0.16	0.11‡	0.067

* Stated crush resistance on datasheet > 1200 kPa
† Maximum pressure stated on datasheet
‡ Intended for longterm use at 500kPa

The in-plane flow reduction per unit of increase in confining pressure was greatest up to 200kPa. This is believed to reflect the change in modulus of the soft foam and non-woven geotextile at 200kPa. Below 200kPa, the soft foam and non-woven geotextile are less stiff and will therefore result in more geotextile intrusion and hence flow reduction will be more rapid. After 200kPa, the boundary materials become stiffer and therefore progressively less geotextile intrusion occurs with each unit of increase of confining pressure.

The bi-planer geonet has a stated crush resistance >1200kPa but the in-plane flow at confining pressures >500kPa was virtually non-existent. This illustrates the irrelevance of short-term compressive strength data, in isolation from the associated in-plane flow, when determining the performance of a geocomposite drain. The single cuspated geocomposite has in-plane flow rates stated up to 500kPa and the tests indicate that at higher confining pressures the flow rate reduced dramatically to virtually nothing at 1000kPa. This illustrates that geocomposites should be used within the limits shown on the datasheets. The heavy duty single cuspate geocomposite whilst intended for use at 500kPa, it maintained a realistic in-plane flow performance even at 1000kPa.

These results are short term tests and the in-plane flow performance over the design life would be reduced due to long term creep. The effect of the long term creep has not been assessed.

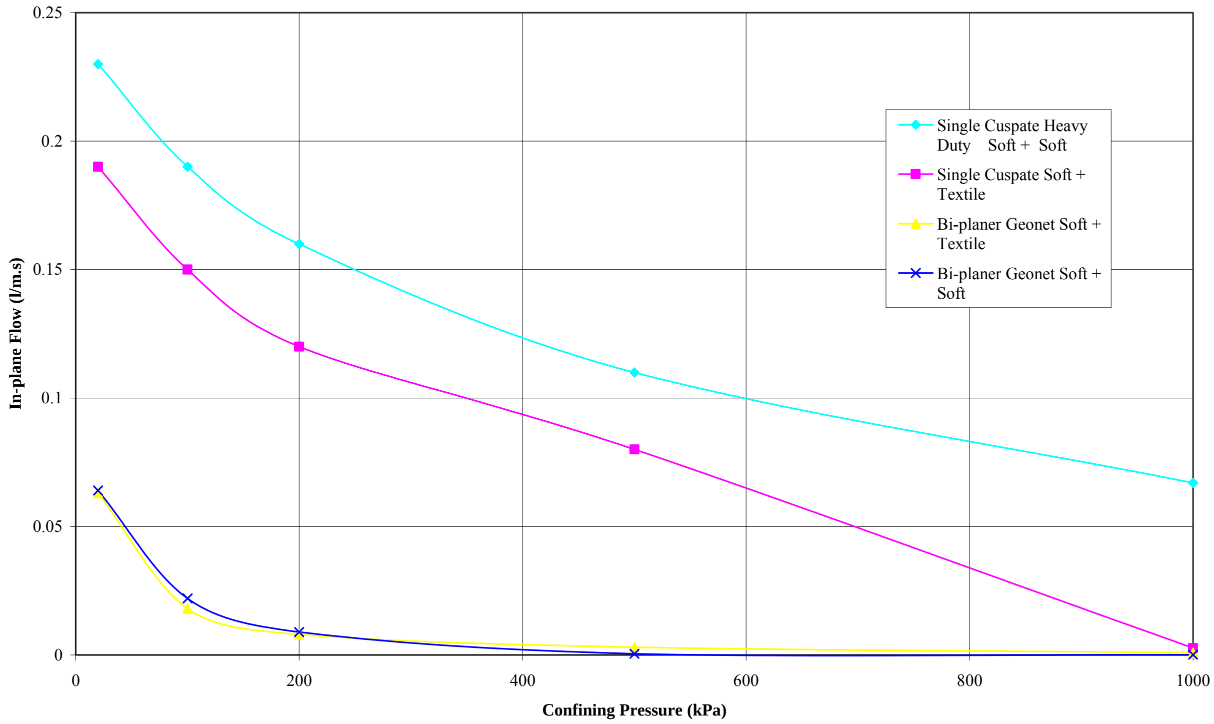

Figure 6. Short-term in-plane flow in machine direction

The heavy duty single cuspated geocomposite has a short term in-plane flow of 0.067l/m/sec at HG 3% at 1000kPa under simulated granular backfill. To put this into context, the in-plane flow of the geocomposite can be compared to the in-plane flow of traditional leachate gravel. The leachate gravel is specified on a permeability k of 1×10^{-3}m/s.

Using Darcy's Law $Q = k\ i\ A \times 10^3$

where Q = flow (l/m/s), k = permeability (m/s), i = hydraulic gradient, A = Area of cross section.

Which for a one metre width of stone 500mm thick becomes.

$$Q_{stone} = k \times i \times (1 \times 0.50) \times 10^3$$

Substituting values

$$Q_{stone} = 1 \times 10^{-3} \times 0.03 \times 0.50 \times 10^3$$

$$= 0.015 \text{ l/m/s}$$

This is less than the short term in-plane flow capacity of the heavy duty single cuspate geocomposite specifically designed for high pressure applications. The factor of safety FOS exceeds 4 and therefore if the long term creep reduction can be shown to be less than 50% over the design life then there is a reasonable long term factor of safety.

If the actual leachate flow values are required, a reduction factor for the viscosity of the leachate compared to water should be applied equally to the gravel and geocomposite.

CONCLUSION

In-plane flow tests using the methodology of EN ISO 12958 but extending the scope to 1000kPa were performed on geocomposites of various forms.

- Closed Cell Foam rubber is less stiff below 200kPa and becomes stiffer at confining pressures up to 1000kPa.
- Direct measurement of in-plane flow of geocomposite drains using closed cell foam (SOFT) platens is more reliable for design than HARD platens and application of a Reduction Factor for geotextile intrusion.
- A design flow reduction factor RFv_T is proposed to correct for the disparity between water temperature in the laboratory and on site.

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REFERENCES

ASTM D1621 2004. Compressive properties of rigid cellular plastics.

ASTM D4716 2007. Determining the (In-plane) flow rate per unit width and Hydraulic transmissivity of a geosynthetic using a constant head.

EN ISO 12958 2007. Geotextiles and geotextile related products. Determination of water flow capacity in their place.

EN ISO 25618-2 2008. Geosynthetics. Determination of compression behaviour. Part 2. Determination of short term compression behaviour.

Greenwood, J.H. & Young, D.K. 2008. Measuring creep of drainage materials by means of the stepped isothermal method in compression. Proc. 4th European Geosynthetics Conference, Edinburgh, September (CD).

Koerner, R.M. 2005. Designing with Geosynthetics.

Zhao, A. & Monrtonelli, F. 1999. Effect of soil pressure on flow capacity of drainage composites under high normal loads.