Evaluation of the Effectiveness of a Granular layer in Preventing Clogging and Blinding of Filter Geotextiles by Clay and Silt size Soil Particles in Sub-soil Drainage Systems

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Abstract

Geotextile filters are frequently used in filtration and drainage applications for road pavement and structural drainage. These filters are prone to clogging by clay and silt particles. A study to evaluate the effectiveness of using a granular layer or washed river sand between the filter and base soil was conducted. A sandy clay soil was used in this study to investigate the performance of various geotextiles in soils with high clay and silt fractions. Two filtration tests with a total duration of 888 hours each were conducted. One test was conducted with 40 mm granular layer between the geotextile filter and the soil sample. The second test was conducted without a granular layer. The purpose of the two tests was to evaluate the effectiveness of the granular layer to maintain flow through a problematic soil and geotextile combination. The results of the study indicated that the granular layer maintained significant flow volumes, although towards the end of both tests partial clogging conditions appeared.

Key words: geotextile, retention, filtration, gradient ratio, permeability

1. Background

Geotextiles have been used in many applications in civil engineering and research is on-going on the improvement of these materials (Miszkowska, 2017; Fannin, 2010; Fannin, 2008; Giroud, 2010; Cazzuffi *et al*, 2015). One of the most critical applications of geotextiles is filtration and drainage (Palmeira *et al*, 2010). The most commonly used types of geotextile in these applications are "thin-grade" polyester and polypropylene non-woven geotextiles due to their ability to permit flow of water and retaining particles of the base soil. Filters are prone to clogging and blocking by fine silt and clay sized particles and this can lead to disastrous consequences like structural failures, premature cracking, pavement deterioration, etc *(Kaytech Filter Design Guide, 2001)*. This paper will focus on the effectiveness of adding washed river sand to the filter design as an easy solution to prevent clogging and blinding of filter geotextiles in sub-soil drainage systems where problematic soils are present.

2. Literature

Geotextile filters have been used as a cost saving solution to replace the use of traditional granular filters which proved to be costly and labour intensive (Palmeira *et al*, 2010; Wu *et al*, 2020). Non-woven polyester and polypropylene are commonly used in sub-soil drainage applications due to their ability to retain particles of the base soil and allowing adequate seepage of water through the geotextile plane (Miszkowska, 2020).

The design of sub-soil drainage systems incorporating geotextile filters can be complex due to the large number of parameters involved (Chen *et al*, 2008). Selection of the appropriate filter can also be a challenge especially when the base soil has a large percentage of silt and clay sized fractions. These soil types are typically the most problematic in sub-soil drainage systems. The filter design is mainly based on two criteria, namely, retention and permeability (Giround, 2020; Moraci, 2010). The retention criterion requires that the pore opening size of a geotextile filter should be small enough to prevent movement of particles of the base soil and is expressed as (Cazzuffi *et al*, 2015):

$$O_F \leq R_R D_n \qquad (1)$$

where: O_F - characteristic opening size of geotextile which is usually O_{95}

R_R – retention ratio

D_n – base soil particle diameter which is usually D_{85}

According to Giround (1996), anti-clogging capabilities should also be considered in the design of geotextile filters.

The permeability criterion suggests that the geotextile filter should be permeable enough to allow flow of water through the plane and is expressed as:

$$k_g \geq k_s \qquad (2)$$

where: *kg – permeability of the geotextile filter*

ks – permeability of the soil

However, the following equations were proposed by the Federal Waterways Engineering and Research Institute, (1993):

$$k_g \geq 10k_s \qquad (3) \qquad \text{for non-cohesive soil}$$

$$k_g \geq 100k_s \qquad (4) \qquad \text{for cohesive soil}$$

An improperly designed filter can lead to clogging, blinding or even piping (Zornberg and Christopher, 2007; Fannin, 2010). Clogging and blinding are the most problematic mechanisms which can lead to reduced flow through the filter and an increase in pore water pressure (Giround, 2010). In most construction projects, sub-soil drainage systems are designed to drain away excess groundwater caused by shallow or fluctuating water tables.

Laboratory testing is often required to test the base soil against geotextile in filtration and drainage applications. The selection of geotextile filters depends on the properties of both the base soil and the filter (Miszkowska, 2017). Some geotextile manufacturers have developed spreadsheets that assist in the selection of filters based on soil grading *(Kaytech Filter Design Guide, 2001).* In cases where the site is underlain by a problematic soil, engineers often opt to use a 300 mm layer of washed river sand between the filter and the base soil to prevent clogging or blinding of the filter. This idea was initially proposed by Kellner (1991) where he suggested the use of a granular layer between clayey in-situ or base soil and the geotextile. He argued that this would enable the formation of a natural filter between the clayey soil and geotextile. During this process, there’s an initial loss of fine particles through the filter but larger particles starts to limit the loss and retain the smaller particles according to the rule of autostability. According to Rollin and Lombard (1988), this process is favoured in well-graded soil.

3. Properties of Geotextile and Soil

A non-woven needle-punched polyester geotextile was selected for this study due to its specific physical and hydraulic properties. The geotextile has a pore size of 136 µm and a high permeability of 4.2 x 10^{-3} m/s. A summary of the properties is given in Table 1.

Table 1: Properties of the geotextile

Geotextile type	**Mass (g/m^{-2})**	**Thickness under 2kPa (mm)**	**Pore opening size (µm)**	**Permeability (m/s)**	**Tensile Strength (kN/m)**
Non-woven needle-punched continuous filament polyester geotextile	233	2.37	136	4.21 x 10^{-3}	13.5

In this experimental study the base soil used was sampled at a platinum mine in Limpopo Province, South Africa and it classified as *sandy clay* according to the particle size distribution. The soil was selected due to its high clay content, high plastic index and low permeability which makes it a potentially problematic soil in sub-soil drainage systems. . It is dark grey to black in colour, with a grading modulus of 0.32, a plasticity index of 32 and low potential expansiveness. According to the Unified Soil Classification System (USCS) the soil falls into the MH group which represents inorganic clayey silts and very fine sands. The physical and hydraulic properties of the soil are summarized in Table 2.

Table 2: Properties of the soil used for the purpose of the study

Composition				**Atterberg limits**			**Permeability (m/s)**	**Soil Classification (USCS)**
Clay (%)	**Silt (%)**	**Sand (%)**	**Gravel (%)**	**Liquid Limit (%)**	**Plastic index (%)**	**Linear Shrinkage (%)**		
61	13	20	6	87	32	24.0	3.66 x 10^{-11}	MH

The geotextile satisfies the above Equations 2, 3 and 4 due to its high permeability of 4.2 x 10^{-3} m/s as compared to the low permeability of the soil at 3.66 x 10^{-11} m/s. However, the poresize of the geotextile at 136 µm is larger than the most dominant particle size of the soil, which is 61% clay.

Figure 1 shows a particle size distribution curve of the sandy clay used in the experiments.

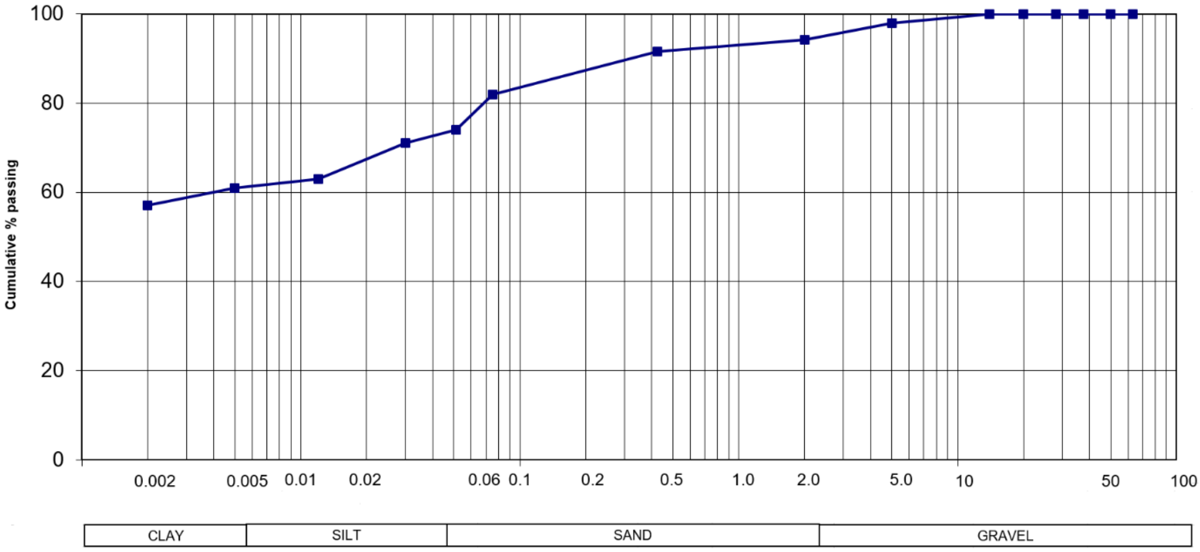

Figure 1: Particle Sze Distribution graph of Sandy Clay

4. Methods

Gradient Ratio test (based on ASTM D5101) is the most commonly used method for evaluating soil-geotextile compatibility. For the purpose of this study, a modified version of this test was used, referred to as the *Long Term Gradient Ratio* (*Kaytech Filter Design Guide*, 2001) due to the long test duration.

Two soil-geotextile filtration compatibility tests were conducted (i.e. Test 1 and Test 2). In Test 1 a layer of granular material sand was placed between the sandy clay and the geotextile. In Test 2 the geotextile was placed directly against the sandy clay soil without the granular material layer (Figure 2). The two systems were each subjected to a total head of 1 500 mm and the tests were run for a total duration of 888 hours. During the test, water is passed vertically across the permeameter through the soil-geotextile interface.

Prior to testing, the sandy clay was oven-dried overnight at 110° C and split into small representative samples for the tests. The geotextile specimen was placed on the lower clamping device with the soil sample deposited on top using a funnel. The upper clamping device was placed and fixed to complete the experimental setup. Wetting of the system was done from the bottom overnight to allow for complete saturation of the soil and geotextile.

Figure 2 shows a schematic diagram of the long term gradient ratio test setup with standpipes 1 to 5 indicated. The standpipes were placed to measure the following:

- standpipe 1 measured the water head at the inlet;
- standpipe 2 measured head inside the permeameter;
- standpipe 3 measured head in the soil sample;
- standpipe 4 measured head at the soil-geotextile interface; and
- standpipe 5 measured head at the outlet.

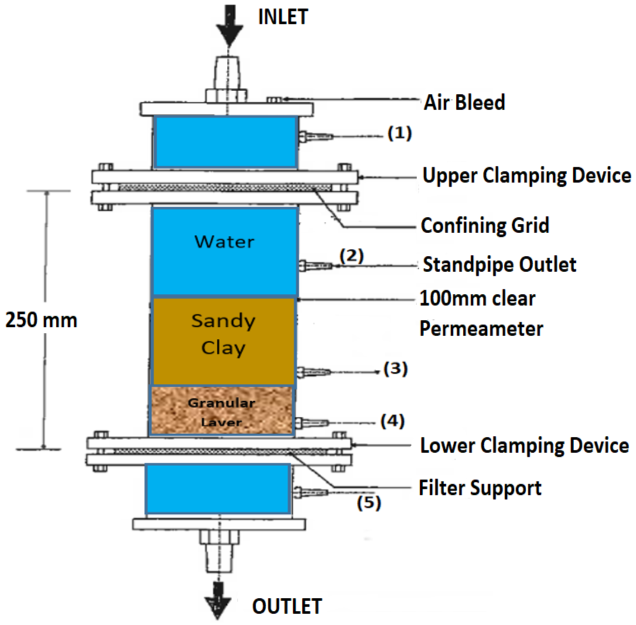

Figure 2: Schematic representation of the permeameter setup (modified from Kaytech)

A test set up for the two tests is presented in Figure 3. Permeameter on the left hand side represents Test 1 and Test 2 is on the right hand side.

Figure 3: Permeameters during the filtration test. Test A is sandy clay and the granular layer. Test B is the sandy clay with no granular layer

5. Discussion of Results

The results from the gradient ratio test indicate that permeability for Test 1 was very high at the beginning ranging between 2.5 x 10^{-6} m/s and 2.1x 10^{-6} m/s and decreased significantly from 72 hours to 1.2 x 10^{-6} m/s. This decrease in permeability continued until the system reached equilibrium at around 624 hours at a permeability of 5.959 x 10^{-7} m/s. The permeability in Test 2 was low from the start at 7.994 x 10^{-7} m/s and decreased significantly at 168 hours to 3.488 x 10^{-7} m/s. Equilibrium in this system was reached at 744 hours with a permeability of 2.326 x 10^{-7} m/s.

Figure 4 shows the performance of the two systems in terms of their permeabilities. Although the permeability of Test 1 decreased significantly, it still remained higher than that of Test 2 until end of the test. It is therefore clear that Test 1 performed better than Test 2.

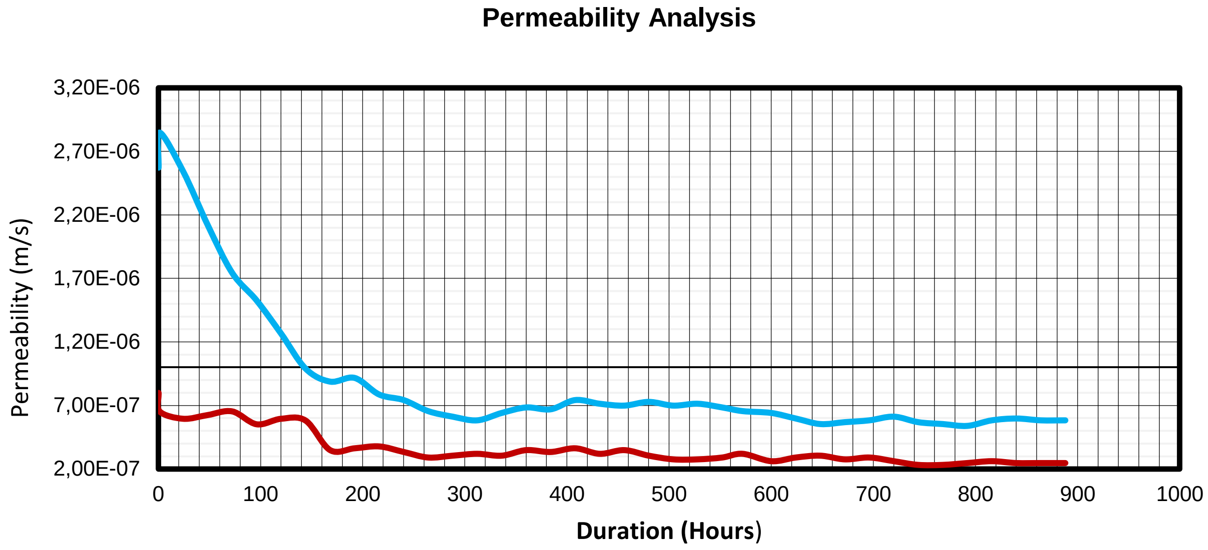

Figure 4: Permeability of the two systems (Test 1 blue & Test 2 red)

The Gradient Ratio (GR) is determined as the ratio of the hydraulic gradient across a soil-geotextile interface to the hydraulic gradient through the soil itself (ASTM D5101). A GR of one or less is preferred in drainage systems. If this value is higher than one partial clogging or clogging conditions are indicated.

Figure 5 presents gradient ratios of the two tests conducted. Test 1 started at a very low GR of 0.2 indicating a more open filter system and gradually increased over time crossing the *"preferred GR line"* at 72 hours. A severe case of clogging was observed between 744 and 792 hours. The system started stabilizing again at 816 hours and ultimately reached equilibrium.

The GR for Test 2 started fairly high at 1.3 in the first few minutes of the test and increased to 3.3 within an hour suggesting fine particles moving into the filter interface or blinding of the filter. This is evidence of the problems experienced with fine particles (typical of the sandy clay soil used) and the clogging and/or blinding caused by these soils. A peak GR of 3.8 was reached at 720 hours followed by a gradual decrease as the system reached equilibrium. The two GR lines crossed for the first time at 216 hours, both above the *"preferred GR line"*. The GR of Test 1 remained significantly lower throughout.

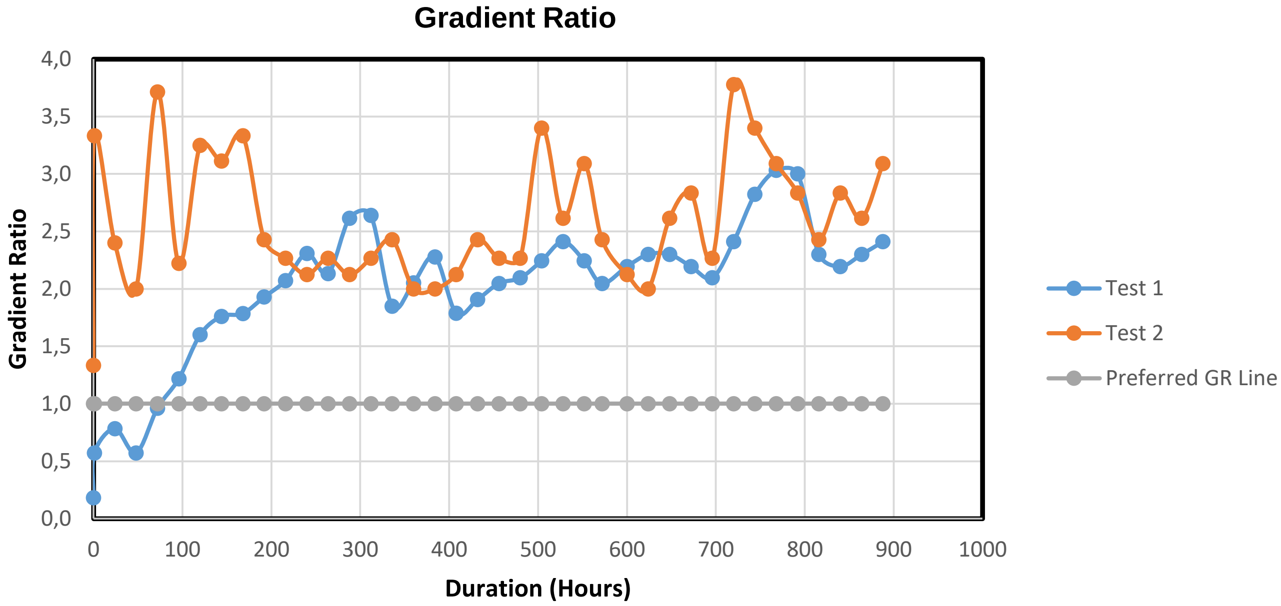

Figure 5: Gradient Ratios of the two systems

6. Analysis

Both tests were run for a maximum duration of 888 hours and the permeabilities and gradient ratios determined for each test were compared. It was observed that Test 1 had overall higher permeability and lower gradient ratios compared to Test 2. Both systems were either partially clogged or blinded at the end of the test duration. However, results from the experiments indicate that the setup for Test 1 with a layer of granular material between the geotextile and the sandy clay is less likely to be clogged or blinded. Test 2 seems much more prone to clogging or blinding by the fine-grained clay/silt particles without the granular layer. The experimental sandy clay soil comprises 61% clay sized particles which are problematic especially in this case where the geotextile pore size of 136 µm is larger than the diameter of the most dominant soil particle size.

Although the pore size of the filter is larger than the most dominant particle size of the soil, the retention of the filter was high at 99.8% for test. This is an unusual case because clay sized particles would have piped through the system and this might have resulted in high permeability and a loss of particles. The loss of fine soil particles can leave voids in the remaining larger particles and ultimately resulting in collapse of the soil structure (Zornberg and Christopher, 2007). However, it is suspected that the fine clay sized particles might have caused blinding on the surface of the filter with some causing partial clogging in the filter.

Table 3 shows the mass of soil and geotextile before and after each test. The retention for Test 1 could not be calculated as the soil and the granular layer could not be separated after test. The retention of soil particles in the filter in Test 2 was 99.8% confirming a high retention (Table 3).

Table 3: Mass of soil samples and geotextiles before and after test

Test No.	Mass soil sample used (g)	Mass of soil sample after test (g)	Mass Geotextile Before test (g)	Mass Geotextile After test (g)	Material entrapped in the geotextile (g)	Material lost during de-assembly (g)	Mass soil caught on filter paper (g)	Soil retained by filter (%)
1	1178.4	-	2.50	2.64	0.14	-	0.0	-
2	1196.7	1186.8	2.40	6.10	3.70	4.22	1.98	99.8

7. Summary and Conclusions

An experimental study on the use of a granular layer to prevent clogging and blinding by clay and silt sized particles of a geotextile in a drainage situation was executed. The conclusions from this study are summarized as follows:

- Two tests were setup in permeameters with Test 1 including a layer of granular material between the sandy clay and the geofabric and the Test 2 setup with the filter directly against the sandy clay.
- The two tests were run for a maximum of 888 hours without being completely clogged at the end of the test, although their Gradient Ratios were both more than 1.
- The best performing system is Test 1 with the conclusion that the presence of the granular layer resulted in a significant improvement in performance of that system.
- Sandy clays are one of the most problematic soils in filtration applications and this is evident from the performance in Test 2. The permeability was low from the start to the end of the test.
- System permeability for Test 1 ranged between 2.849 x 10^{-6} m/s and 5.378 x 10^{-7} m/s throughout the test duration. The peak permeability was recorded in the first hour of the test.
- System permeability for Test 2 ranged between 7.994 x 10^{-7} m/s and 2.471 x 10^{-7} m/s. The peak permeability was also recorded in the first hour of the test.
- Although the geotextile pore size was not ideal in the experimental setup the performance of the system with an additional layer of granular material between a problem soil and filter is evident.

- It is recommended that an additional granular layer is installed between fine-grained problem soils and filters to enhance the filter performance and prevent longterm clogging and/or blinding.
- The selection of an appropriate geotextile pore size will also enhance the long term performance of subsoil drainage systems.

8. References

ASTM D 5101. Standard Test Method for Measuring the Filtration Compatibility of Soil-Geotextile Systems. ASTM International, USA.

Bundesanstalt fur Wasserbau (1993). Code of practice for the use of geotextile filters on waterways. *The Federal Waterways Engineering Research Institute in Germany, Karlsruche*

Cazzuffi, D., Lelo, D., Mandaglio, M.M., and Moraci, N. (2015). Recent developments in the design of geotextile filters. *The 2nd International GSI-Asia Geosynthetics Conference, Seoul, Korea, June 24-26, 2015.*

Chen, R.H., Ho, C.C., and Chung, W.B. (2008). The filtration mechanism and micro-observation of soil-geotextile systems under cyclic flows. Journal of Geoengineering, vol.3, pp. 101-112.

Giroud J.P. (1996). Granular filters and geotextile filters. Proc.Geofilters ’96, Montreal, Canada, pp. 565-680.

Giroud, J.P. (2010). Development criteria for geotextile and granular filters. Proceedings, 9th international Conference on Geosynthetics, Brazil 2010, pp. 45-64.

Kellner, L and Matei, S. (1991). Criteria for geotextile filters in clayey soils, *geotextiles and geomembranes.* Elsevier, 9, 79-88.

Miszkowska A, Koda E, Krzywosz Z. Effect of the Number of Constrictions on the Filtration Behaviour of a Soil-Geotextile System. *Fibres & Textiles* in Eastern Europe 2020; 28, 1(139): 87-92. **DOI:** 10.5604/01.3001.0013.5862 .

Rollin, A. L. and Lombard, G. (1988) Mechanisms affecting long-term filtration behaviour of geotextile, *Geotextiles and Geomembranes*, Elsevier, 7, 119-145.

Wu, H., Yao, C., Li, C., Miao, M., Lu, Y., Liu T. (2020). Review of application and innovation of Geotextiles in Geotechnical Engineering. Materials (2020), 13, 1774; DOI:10.3390.