# Comparison of Geosynthetic and Granular Leachate Collection Systems

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**ABSTRACT:** This paper will discuss some of the critical aspects of the design and use of geosynthetic leachate collection systems, including the use of available design methods and reduction factor procedures. The choice of appropriate test methods will be discussed, and a summary of the results of testing carried out for a geosynthetic drainage system for a 50 metre deep landfill will be presented.

## 1 INTRODUCTION

The use of landfill liner and drainage systems commenced in locations where there was a ready supply of clay and gravel, and it became common practice to use a 900 mm thick compacted clay liner overlain with a 300 mm thick gravel leachate collection and drainage layer. The origins of the gravel drainage layer thickness may have been more of an empirical nature than rigorous design.

With the advent of geosynthetic systems, it has now become common practice for the liner to comprise a composite of a geomembrane and a geosynthetic clay liner, and for the drainage layers to be based on geonets with geotextile filters. These geosynthetic drainage layers are often designed incorrectly on the basis of simple transmissivity equivalency to traditional gravel layers, rather than a hydraulic performance assessment.

Geosynthetic leachate collection systems have been used widely since the mid 1990s. They have largely replaced conventional gravel drainage layers on landfill side slopes and there are many advantages of using these systems. Design methods have now been published for the use of geosynthetic drainage systems as alternatives to gravel drainage layers. However, there is still some concern regarding clogging of geosynthetic leachate collection systems.

This paper will discuss some of the critical aspects of the design and use of geosynthetic leachate collection systems. Appropriate test methods will be discussed, and the results of testing carried out for a 50 metre deep landfill will be presented.

Regulatory approval required compliance with guidelines which recommended a gravel drainage layer across the entire base of the landfill. The guidelines suggested a gravel layer with a thickness of 300 mm and a coefficient of permeability greater than $1 \times 10^{-3}$ m/sec. The regulator suggested that the drainage media should be selected to have sufficiently large pore spaces to prevent encrustation, and drew attention to the discussion of geotextile clogging contained in Rowe and Van Gulck (2001).

This led to the emergence of two essential design tasks:

- To determine the correct equivalency of the geosynthetic system performance to the granular system provided by regulatory guidance, and
- To determine the adequacy of the system to accommodate calculated fluid flows with adequate factors of safety after consideration of potential for performance reduction by various factors.

## 2 BACKGROUND

In the early use of geotextile filters, they were often placed in the incorrect location (on the downflow or discharge side of the drainage layer, instead of the inflow side) and clogging became a noticeable problem. This clogging problem was observed in both drainage layers comprising gravel and drainage layers comprising geonets, and was not particularly related to the type of drainage layer material.

Clogging occurs when fine material flows through the drainage system and blocks small pore spaces, or when chemical precipitation or biological growth occurs within the pore spaces. Clogging is related to the flow through the critical component of the system, the void sizes, the temperature in the collection system, the leachate chemistry and the saturation or dryness of the system. Some types of waste will generate leachate that will initiate clogging more than others. In addition, the void size can be reduced by the high compressive forces generated by large depths of waste.

It is to be emphasised that clogging is associated with the wrong sized holes, or pore spaces, in the drainage system and is not related to the type of material forming the sides, or walls, of those holes. A poorly designed gravel leachate drainage layer will be just as susceptible to clogging as a poorly designed geonet leachate drainage layer, and conversely a well designed geonet leachate drainage layer will perform as satisfactorily as a well designed gravel leachate drainage layer.

A review of the literature in relation to leachate clogging of drainage layers yielded the following key points:

- Fully and continuously saturated systems are less susceptible to chemical and biological clogging (Knox, 2000)
- Clogging is more likely with filters placed in flow concentrations than with larger area blanket filters and the critical factors are the void or pore size, the temperature and leachate chemistry and the flow through the critical elements (Rowe and VanGulck, 2001).

The authors have observed problems that have been caused by flow constrictions in drainage systems in landfills in Hong Kong and Australia (especially at the exits of drainage layers), and it is recommended that flow constrictions are avoided. The authors have also observed clogging of gravel leachate drainage layers in Germany, Hong Kong and New Zealand. In each case, it was apparent that the gravel contained too many fines. That is, the size of the holes was not large enough, and also the fines resulted in a tortuous pathway through the gravel. An advantage of geocomposite drains is that the flow path through the geonet drainage core is relatively straight.

Geosynthetic leachate collection systems have been used extensively in the USA, and other parts of the world, since the mid 1990s. Often the geocomposite drain has been used in side slope leachate collection systems or in the leakage detection system beneath the liner.

In addition, design methods have been published for the use of geosynthetic drainage systems for leachate collection systems in landfills (eg. Bonaparte et al, 1985; Giroud and Houlihan, 1995; Giroud et al, 2000a; and Giroud et al, 2000b).

## 3 DEVELOPMENT OF LEACHATE COLLECTION SYSTEM DESIGN

### 3.1 *Equivalency and Initial Design Basis*

A design concept was initially developed for the landfill based on the equivalency design method published by Giroud et al (2000), and the following assumptions:

- A geocomposite drainage layer (comprising a geonet drainage core and geotextile filters) will be laid across the entire base of the landfill at a sloping gradient of 2%
- The geocomposite drainage layer is to be more than equivalent to the guideline gravel drainage layer

- Leachate collection pipes will be placed at regular intervals across the base, within trenches filled with gravel, with adequate connection with the geocomposite, to drain the liquid from the geocomposite drainage layer.

The guideline gravel drainage layer has a thickness, t, of 300 mm and a coefficient of permeability, k, of $1 \times 10^{-3}$ m/sec. Giroud et al (2000) have shown that simple selection of a geonet with the same transmissivity as a gravel layer will result in a system with performance that is less then desired. For an equivalent geonet drainage layer, Giroud et al (2000), show that the transmissivity, θ, of the geonet should be:

$$\theta = \frac{k.t}{0.88} + \frac{k.t^2}{(0.88)^2 \times L} \times \frac{\cos\beta}{\tan\beta}$$

where, L = the distance between the drainage pipes
β = the slope angle = 1.14° for a 2% gradient
0.88 = a constant

Initially selecting a 45 m distance between the drainage pipes, the required transmissivity of the geonet was $4.7 \times 10^{-4}$ $m^2$/sec. In order to provide a factor of safety of 2 for the flow capacity of the geonet, it was recommended that this transmissivity value be doubled to $1 \times 10^{-3}$ $m^2$/sec. In order to provide a further factor of safety of nearly 2 against clogging, it was recommended that the distance between drainage pipes be reduced to 25 m.

In addition, it was recommended that the transmissivity of the geonet should be not less than $1 \times 10^{-3}$ $m^2$/sec under the normal load to be exerted by the waste (conservatively estimated to be 1,000 kPa) and a standard hydraulic gradient of 1. As a further precaution, it was suggested that a tri-planar geonet be selected in order to adequately withstand the crushing force of the overlying waste. Specific materials testing was recommended to determine whether the geonet would have adequate flow characteristics under the design load, whether the geotextile would be compatible with the soil material to be placed in contact with it, and whether the geotextile layers would protrude into the drainage void space of the geonet.

It was recommended that drainage pipes be installed across the base of the landfill at a spacing of 25 metres, that these pipes be placed in trenches, and the trenches filled with gravel with the geonet drainage core in direct contact with the gravel. To achieve this, the lower geotextile would need to be placed underneath the gravel.

### 3.2 *Real Flow Design Basis*

Review of the initial equivalency basis for the design led to a desire to confirm the design performance of the geosynthetic system based on the assessed real flows in the system. A separate hydrogeological analysis provided base data for the anticipated flow into the drainage system.

Based on this flow data, it was determined that the geosynthetic drainage system should be examined to demonstrate that the geonet drainage capacity, and the geotextile filter flow capacity, with consideration of reduction factors as proposed by Koerner (1997), would be adequate for the flow rates.

### 3.3 *Adjusted System Design*

It was decided to test a 10 mm thick tri-planar high density polyethylene geonet, covered on both sides with a polypropylene nonwoven geotextile (with no heat bonding), with a clean sand cover layer placed on the upper surface.

A clean sand cover layer was selected in order to minimise clogging potential, the size of the geonet was increased in order to ensure an adequate flow rate, and the geotextile selected in order to minimise clogging. In addition, polyethylene and polypropylene materials were selected as they have a good chemical resistance to leachate. Giroud et al (1998) discuss the influence of sands with a significant fraction of fine particles less than 120 microns in size. They point out that this fraction of fine particles can give rise to some clogging potential. By contrast, the sand proposed for this landfill had less than 2% particles smaller than 150 microns, and this potential was therefore minimised.

## 3.4 *System Testing*

Two types of performance testing of the materials and systems were carried out:

- Flow rate (transmissivity) testing of the complete system with cover soil each side to establish that the flow reduction due to intrusion is not significant.
- Soil and geotextile permeameter testing with the soil material that will be placed on top of the leachate drainage layer to establish that the geotextile can adequately protect the geonet without clogging by fine particles.

The transmissivity tests were carried out in accordance with the ASTM standard test method D4716 for determining the in plane flow rate per unit width and hydraulic transmissivity of a geosynthetic using a constant head. The drainage system was formed with (from top to bottom) sand, non-woven geotextile, geonet and a non-woven geotextile.

One set of transmissivity tests was performed under four hydraulic gradients: 1.0, 0.5, 0.25 and 0.1, and seven increments of applied load: 20, 50, 100, 200, 600, 800 and 1000 kPa. In addition, the tests carried out under an applied load of 1000 kPa were continued for over 200 hours in order to have an initial evaluation of compressive creep effects. Another set was performed under three hydraulic gradients: 1.0, 0.25 and 0.1, and four increments of applied load: 200, 600, 800 and 1000 kPa.

The hydraulic conductivity, or permeameter, tests were carried out in accordance with the ASTM standard test method D5567 for hydraulic conductivity ratio testing of soil/geotextile systems. This method was selected as it enabled the test to be conducted under the design loads. The filtration system was formed with sand, a non-woven geotextile and a tri-planar geonet.

The permeameter tests were performed under a load of 1000 kPa and a hydraulic gradient of 1.0. Stability of flow for each system was achieved very quickly (in about 30 minutes) and the tests were continued until this stability was confirmed.

## 3.5 *Reduction Factors*

Koerner (1997) recommends five reduction factors for the formulation of allowable flow rates through a geotextile and four reduction factors for determining the allowable flow rate, or transmissivity, of geonets. The five reduction factors for geotextiles are for soil clogging and blinding, creep reduction of voids, intrusion into voids, chemical clogging and biological clogging. The four reduction factors for geonets are for intrusion of the adjacent geotextile into the geonet’s core space, creep deformation, chemical clogging and biological clogging.

The recommended values for these reduction factors vary depending on their criticality and uncertainties at the time of design. Koerner (1997) states that if measured data is available then the values of the reduction factors can be lower (and could be as low as unity) than for situations where there is more uncertainty. In addition to these reduction factors, a suitable overall factor of safety needs to be achieved or applied to the project.

After consideration of the available data from the tests, the reduction factors were assessed for the geotextile filter and the geonet drainage layer as set out below.

### *3.6.1 Geotextile Filter*

*Soil Clogging*: The permeameter, or hydraulic conductivity, tests provided good quality data on the site situation. Therefore, this reduction factor was taken as 1.0.

*Creep Reduction*: Little data was available, so this reduction factor was taken as 2.0.

*Intrusion into Voids*: The permeameter tests provided good quality data on the site situation. Therefore, this reduction factor was taken as 1.0.

*Chemical and Biological Clogging*: The proposed landfill would not be permitted to accept domestic and putrescible waste, and was intended to replace the adjacent existing landfill. Rowe and Van Gulck’s (2001) observations of clogging were made in domestic waste landfills.

Monitoring at the adjacent landfill showed that the resulting leachate was weak compared to a domestic waste landfill. The oxidation reduction potential values were positive, rather than negative, and the ammonia content and biological oxidation demand (BOD) values were low. The monitoring data showed that the liquids to be filtered and drained by the drainage system at the new landfill would have a low clogging potential.

For chemical clogging, Koerner (1997) recommends a range of reduction factors from 1.2 to 1.5. Therefore, the chemical clogging reduction factor was taken as 1.2. For biological clogging, Koerner (1997) recommends a range of reduction factors from 5 to 10. Therefore, the biological clogging reduction factor was taken as 5.

Resulting combined reduction factor for the geotextile:

$RF_{comb} = RF_{scb} \times RF_{cr} \times RF_{in} \times RF_{cc} \times RF_{bc} = 1.0 \times 2.0 \times 1.0 \times 1.2 \times 5.0 = 12$

### *3.6.2 Geonet Drainage Layer*

*Intrusion*: The transmissivity tests provided good quality data on the site situation. Therefore, this reduction factor was taken as 1.0.

*Creep*: The geonet proposed and tested for this project was a relatively new product at the top end of an existing range of tri-planar geonets. This range of products has a long history of compression creep testing. Although a standard 10,000 hour creep test had not yet been completed on this product, the transmissivity test under 1000 kPa had been carried out for over 200 hours, which allowed some comparison with the creep data for the rest of the range. Koerner (1997) recommends a range of reduction factors for creep from 1.4 to 2.0. After consideration of the creep test data, it was decided that this reduction factor could be taken as 1.9.

*Chemical and Biological Clogging*: As discussed above in the geotextile section, the monitoring data showed that the liquids to be filtered and drained by the drainage system at the landfill will have a low clogging potential. For both chemical and biological clogging, Prof. Koerner recommends a range of reduction factors from 1.5 to 2.0. Therefore, both the chemical and biological clogging reduction factors were taken as 1.5.

Resulting combined reduction factor for the geonet:

$RF_{comb} = RF_{in} \times RF_{cr} \times RF_{cc} \times RF_{bc} = 1.0 \times 1.9 \times 1.5 \times 1.5 = 4.28$

## **3.7 *Design Flow Rates***

The maximum inflow rate was determined by others to be 3.3 mm/m$^2$/day. This equates to a flow rate of $3.82 \times 10^{-8}$ m$^3$/m$^2$/sec (or m/sec).

### *3.7.1 Geonet Transmissivity*

Using the equation for the required hydraulic transmissivity given Giroud et al (2000b):

$$\theta_{req} = FS \times RF_{comb} \times q \times L / \sin \beta$$

where:

$\theta_{req}$ = required transmissivity
FS = overall factor of safety
$RF_{comb}$ = combined reduction factor for geonet = 4.28
q = maximum inflow rate = $3.82 \times 10^{-8}$ m$^3$/m$^2$/sec
L = distance between drainage pipes = 25 m
$\beta$ = slope angle = 1.14° for a 2% drainage gradient

therefore: $\theta_{req} / FS = 4.28 \times 3.82 \times 10^{-8} \times 25 / \sin 1.14°$

$\theta_{req} / FS = 409 \times 10^{-8} / 0.02 = 0.204 \times 10^{-3}\ m^2/sec$

### *3.7.2 Geotextile Hydraulic Conductivity*

For the geotextile, the required maximum inflow rate is $3.82 \times 10^{-8}$ m/sec. Taking a combined reduction factor for the geotextile of 12, then the required measured flow rate, or hydraulic conductivity, k, of the geotextile under a 1000 kPa load is:

$k = 3.82 \times 10^{-8} \times 12 \times FS$

$k/ FS = 0.458 \times 10^{-6}$ m/sec

### 3.8 *System Test Results*

It was determined that the maximum possible hydraulic gradient in the drainage system would be 0.6 (based on a maximum possible leachate head of 15 m and a spacing of 25 m between drainage pipes: 15/25 = 0.6). The geonet transmissivity test results showed that

- for a hydraulic gradient of 0.5 the transmissivity of the drainage system was $2.1 \times 10^{-3}\ m^2/sec$
- for a hydraulic gradient of 1.0 the transmissivity of the drainage system was $1.5 \times 10^{-3}\ m^2/sec$.

Extrapolating between the two, it was estimated that the transmissivity of the geonet drainage system under a load of 1000 kPa and a hydraulic gradient of 0.6 was $2.01 \times 10^{-3}\ m^2/sec$.

Therefore, $FS_{geonet} = \dfrac{2.01 \times 10^{-3}}{0.204 \times 10^{-3}} = 9.85$

The hydraulic conductivity tests on the geotextile filter system reached a stable flow situation in about 30 minutes. The minimum hydraulic conductivity that was measured was $3.30 \times 10^{-6}$ m/sec

Therefore, $FS_{geotextile} = \dfrac{3.30 \times 10^{-6}}{0.458 \times 10^{-6}} = 7.2$

## 4 CONCLUSIONS

A leachate drainage system for a new landfill was developed based on a high capacity tri-planar geonet, with a non woven geotextile filter, covered with a layer of clean sand.

This drainage system was tested for clogging potential and long term flow, and:

- It was demonstrated to be capable of equivalent or better performance under the site conditions than the granular layer prescribed by regulatory guidance.
- It was demonstrated that the geonet drainage capacity, with consideration of reduction factors as proposed by Koerner (1997), achieved an overall factor of safety of nearly 10 for the design flow rates.
- It was demonstrated that the geotextile filter flow capacity, with consideration of reduction factors as proposed by Koerner (1997), achieved an overall factor of safety of more than 7 for the design flow rates.

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