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DIMENSIONING THE INTERDRAIN GEOCOMPOSITE FOR DRAINING OFF INFILTRATED RAIN WATER FROM A LANDFILL CAP

STUDY CONTENTS:

1. PROPOSED METHODS

Intermas Geosynthetics suggests two methods for dimensioning the drainage capacity of the INTERDRAIN geocomposite in landfill caps.

- based on the permeability of the covering soil
- based on the rainfall measurements in the area

In the two methods, the INTERDRAIN geocomposite is dimensioned so that it has a drainage capacity greater than the maximum amount of rainwater than can infiltrate the landfill. In these conditions, the water pressure will be less than the thickness of the drainage geocomposite, so the water circulates in the free layer and prevents the covering soil becoming saturated.

If the covering soil were to be saturated, the hydrostatic pressure would increase, and the friction between the layers of geosynthetics would be reduced, so the risk of a landslide on the cap slopes would increase.

In the flat areas of the landfill, there is no landslide risk so, although it is necessary and essential to have a drainage system, it is not essential to ensure that the capacity of the drainage system is greater than the amount of infiltrated water.

Because of the above, this calculation particularly applies to cap slopes.

Before beginning to explain the two proposed methods, we will calculate the maximum drainage capacity of standard INTERDRAIN geocomposites (short and long term) when operating as a drainage system in landfill caps.

2. CALCULATING THE DRAINAGE CAPACITY OF INTERDRAIN

The drainage capacity of a drainage geocomposites estimated using the Transmissivity Test (ISO 12958) and depends on 3 factors:

- Hydraulic gradient
- Normal INTERDRAIN pressure on the plane
- Surrounding conditions

This calculation is the result of our revised and corrected knowledge. INTERMAS refuses to accept any responsibility deriving from its use in works schemes and provides it purely for information purposes.

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2.1. PRESSURE

If the INTERDRAIN drainage geocomposite is fitted horizontally, the normal pressure on the plane ($\sigma_{v.}$) of INTERDRAIN will correspond to the weight of the covering soil:

$\sigma_v = \gamma \cdot h + q$

Where:

- γ: weight of earth (kN/m^3)
- h: height of earth (m)
- q: Overload (kN/m = kPa)

Assuming usual values of γ = 17 kN/m^3, H = 0.8 m and q = 0 kPa, we obtain:

$\sigma_{v.} = \gamma \cdot H + q = (17 \times 0.8) + 0 = 13.6$ kN/m2 = 13.6 kPa

If INTERDRAIN is fitted on a slope, the normal pressure on the plane will be lower than this value. A value for pressure on INTERDRAIN ofσ=20 kPa is a conservative one in the majority of situations.

2.2. HYDRAULIC GRADIENT

The hydraulic gradient generated inside the geocomposite is $i = \frac{\delta h}{L}$ = sine β, where:

- δh: loss of pressure head of the fluid drained by the geocomposite (m).
- L: distance between two points of the drain (drain pipe) along the direction of the flow (m).
- β: Slope angle.

2.3. SURROUNDING CONDITIONS

The transmissivity test can be carried out using 2 plates:

- rigid aluminium plates (simulating rigid contact, such as a geomembrane or concrete)
- flexible neoprene plates (simulating flexible contact, such as soil or a layer of bentonite)

At low pressures (up to 30 kPa) the differences between the drainage values in different surrounding conditions are not very significant.

2.4. CALCULATING THE SHORT-TERM DRAINAGE CAPACITY OF INTERDRAIN

Using the ISO 12958 standard, we obtain the drainage capacity of INTERDRAIN geocomposites submitted to 20 kPa pressure and hydraulic gradients i=1, i=0.5 e i=0.1. When the actual hydraulic gradient does not correspond to one of those tested (i=1, i=0.5 e i=0.1), Rimoldi's expression is used to estimate the actual drainage capacity.

$$q_{i2} = q_{i1} \frac{\sqrt{i_2}}{\sqrt{i_1}}$$ *(Rimoldi, 1989)*

Where:

- q: $_{i1}$ = drainage capacity corresponding to the gradient tested i= i_1
- q: $_{i2}$ = unknown drainage capacity corresponding to the untested gradient i= i_2
- i_1 = tested hydraulic gradient immediately above the untested gradient (i_2)
- i_2 = untested hydraulic gradient

The following table shows the short-term capacities of INTERDRAIN submitted to 20 kPa and different hydraulic gradients:

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LANDFILL CHARACTERISTICS			DRAINAGE CAPACITY OF INTERDRAIN ($q_{INTERDRAIN}$)					
gradient -	slope angle º	pressure kPa	$q_{GMG\ 412}$ l/s/m	$q_{GMG\ 512}$ l/s/m	$q_{GLG\ 612}$ l/s/m	$q_{GM\ 412}$ l/s/m	$q_{GM\ 512}$ l/s/m	$q_{GL\ 612}$ l/s/m
0.02	1.15	20	0.06	0.11	0.17	0.13	0.15	0.23
0.05	2.87	20	0.09	0.16	0.27	0.21	0.23	0.36
0.1	5.74	20	0.13	0.28	0.38	0.30	0.33	0.51
0.2	11.54	20	0.22	0.42	0.58	0.52	0.59	0.81
0.3	17.46	20	0.27	0.51	0.71	0.64	0.73	1.00
0.4	23.58	20	0.31	0.60	0.82	0.74	0.84	1.15
0.5	30	20	0.35	0.67	0.92	0.83	0.94	1.28
0.6	36.87	20	0.48	0.90	1.16	0.98	1.27	1.48
0.7	44.43	20	0.52	0.97	1.25	1.05	1.37	1.60
0.8	53.13	20	0.55	1.04	1.34	1.13	1.47	1.71
0.9	64.16	20	0.59	1.10	1.43	1.19	1.56	1.81
1	90	20	0.62	1.16	1.50	1.26	1.64	1.91

Table 1. Short-term drainage capacity of INTERDRAIN drainage geocomposites submitted to 20 kPa pressure (landfill cap) and at different gradients. Source: INTERMAS NETS S.A.

2.5. LONG-TERM DRAINAGE CAPACITY OF INTERDRAIN

The long-term drainage capacity of geocomposites does not correspond to that obtained in the transmissivity test. It must be reduced by reduction factors taking into account creep, intrusion of the geotextile into the geonet and chemical and biological silting.

$q_{long\ term} = q_{test} / (RF_{in} \cdot RF_{cc} \cdot RF_{bc} \cdot RF_{cr})$ (GRI Standard)

The reduction factors are described in the following table (www.landfilldesign.com):

- RF_{in} : reduction factor for elastic deformation or intrusion of geotextiles into the geonet.
- RF_{cc}: reduction factor for chemical silting and/or precipitation of chemical agents into the space occupied by the drainage geonet.
- RF_{bc}: reduction factor for biological silting in the space occupied by the geonet
- RF_{cr}: reduction factor for the effect of creep.
- $q_{long\ term}$: actual long-term drainage capacity of the geocomposite
- q_{test}: drainage capacity of the geocomposite obtained from the transmissivity test.

In closing a landfill, the reduction factors of the drainage geocomposites used for draining off rainwater are the following (www.landfilldesign.com):

- RF_{in} = 1.0 – 1.2
- RF_{cr}= depending on the type of geocomposite = 1.19 (case of INTERDRAIN geocomposites)
- RF_{cc} = 1.0 – 1.2
- RF_{bc} = 1.2 – 3.5

The calculations of RF_{cr} for INTERDRAIN are attached in appendix 1.

3. DIMENSIONING INTERDRAIN BASED ON THE PERMEABILITY OF THE COVERING SOIL

This design method is based on dimensioning the INTERDRAIN drainage geocomposite so that it has a drainage capacity greater than the infiltrated rainwater. The maximum value for the infiltrated rain water in the slope is estimated using Darcy's Law, based on the permeability of the covering soil.

It is a conservative method, as the permeability of the covering soil tells us the maximum quantity of water that can infiltrate it.

This method is recommended when the permeability of the covering soil is known.

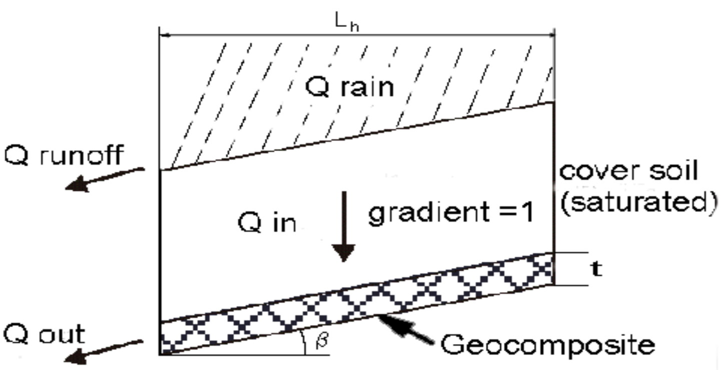

Figure 1. Diagram of water flows in a cap. Source: www.landfilldesign.com

The maximum quantity of water passing through the covering soil is estimated using Darcy's Law:

$Q = K \cdot i \cdot A$

Where:

- Q: = Q_{IN} = water flow passing through the covering soil (m3/s)
- K = $K_{coverage}$ = permeability of the covering soil (m/s)
- i = hydraulic gradient = 1 (the infiltration flow is vertical) (adimensional)
- A = Area = $L_h \cdot 1$ (m2)
- L_h = Horizontal projection of the length of the slope (m)

$Q_{IN} = K_{cover} \cdot 1 \cdot L_h \cdot 1$

Q_{IN} is the maximum quantity of water that will reach the drainage geocomposite. The INTERDRAIN drainage composite in the actual conditions on site must therefore drain more than Q_{IN}:

$\mathbf{Q_{INTERDRAIN} > Q_{IN} = K_{cover} \cdot L_h}$

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4 EXAMPLE OF THE FIRST METHOD

4.1. HYPOTHESES

Suppose that an INTERDRAIN drainage geocomposite must be fitted to drain the infiltrated rain water from the slope of a landfill with the following characteristics:

- L = Length of the slope = 15 m
- β = Angle of the slope = 24º
- h = Height of the covering soil
- Permeability of the covering soil = 10^{-6}m/s

The drainage geocomposite used will be from the GMG range.

4.2. CALCULATING THE MAXIMUM QUANTITY OF WATER INTERDRAIN MUST DRAIN OFF

$Q_{\text{INTERDRAIN}} > Q_{\text{IN}} = K_{\text{cover}} \cdot L_h$
$Q_{\text{INTERDRAIN}}$ > $10^{-6} \cdot L \cdot \cos\beta = 10^{-6} \cdot 15 \cdot \cos 24º = 1.37 \cdot 10\text{-}5\ m^3/m\cdot s =$ **0.014 l/m·s**

The hydraulic gradient generated inside the geocomposite will be I = sine 24º = 0.4.

4.3. DRAINAGE CAPACITY OF INTERDRAIN

From table 1 we choose the row corresponding to i=0.4 and we obtain the drainage capacities of the different INTERDRAIN drainage geocomposites:

gradient -	slope angle º	pressure kPa	$q_{\text{GMG 412}}$ l/s/m	$q_{\text{GMG 512}}$ l/s/m	$q_{\text{GLG 612}}$ l/s/m	$q_{\text{GM 412}}$ l/s/m	$q_{\text{GM 512}}$ l/s/m	$q_{\text{GL 612}}$ l/s/m
0.4	23.58	20	0.31	0.60	0.82	0.74	0.84	1.15

Table 2. Short-term drainage capacity of INTERDRAIN submitted to i=0.4 and σ=20 kPa. Source: INTERMAS NETS S.A.

4.4. LONG-TERM DRAINAGE CAPACITY OF INTERDRAIN

$RF_{in} \cdot RF_{cc} \cdot RF_{bc} \cdot RF_{cr} = 1.1 \cdot 1.19 \cdot 1.1 \cdot 2 = 2.88$

gradient -	slope angle º	Pressure kPa	$q_{\text{GMG 412}}$ l/s/m	$q_{\text{GMG 512}}$ l/s/m	$q_{\text{GLG 612}}$ l/s/m	$q_{\text{GM 412}}$ l/s/m	$q_{\text{GM 512}}$ l/s/m	$q_{\text{GL 612}}$ l/s/m
0.4	23.58	20	0.11	0.21	0.28	0.26	0.29	0.40

Table 3. Long-term drainage capacity of INTERDRAIN submitted to i=0.4 and σ=20kPa. Source: INTERMAS NETS S.A.

4.5. CALCULATING THE SAFETY FACTOR

- **$SF_{\text{GMG 412}}$** $= q_{\text{GMG 412}} / q_{\text{IN}} = 0.11 / 0.014$ **= 7.8**
- **$SF_{\text{GMG 512}}$ =** $q_{\text{GMG 512}} / q_{\text{IN}} = 0.21 / 0.014$ **= 15**
- **$SF_{\text{GLG 612}}$ =** $q_{\text{GLG 612}} / q_{\text{IN}} = 0.28 / 0.014$ **= 20**

The whole INTERDRAIN range ensures the correct drainage.

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5. DIMENSIONING INTERDRAIN BASED ON RAINFALL MEASUREMENTS

When it is not possible to estimate the permeability of the covering soil, you are recommended to use this second method, based on associating an infiltration coefficient with the rainfall measurements for the area.

5.1. CALCULATION METHOD

Of the total amount of rain falling on a landfill slope, the majority will become surface run-off, another part will evaporate or be absorbed by the vegetation (evaporation and evapo-transpiration processes) and the rest will infiltrate into the landfill.

$$Q_{rain} = Q_{surface\ run\text{-}off} + Q_{EVT/EV} + Q_{infiltration}$$

$Q_{infiltration}$ can be estimated by associating a certain infiltration coefficient (f), which will depend on various factors (surface inclination, type and quantity of vegetation, permeability of the ground, etc.)..

$$Q_{infiltration} = f \cdot Q_{rain}$$

5.2. HYPOTHESES

Two calculation situations can be considered:

Situation A) First year of operation of the closure
Situation B) Definitive capping

The first situation (A) happens when the vegetation has not yet fully developed. The second situation (B) happens when the vegetation has fully developed.

Hypothesis for situation A):

- Design rain water corresponds to a return period T=2 years
- $Q_{EVT/EV} = 0$
- Infiltration coefficient (conservative values):
  - o $f_{flat\ areas} = 0.6 - 0.8$
  - o $f_{slopes} = 0.3 – 0.4$

Hypothesis for situation B):

- Design rain water corresponding to T=25 years (value used in caps)
- $Q_{EVT/EV} > 0$
- Infiltration coefficient (conservative values):
  - o $f_{flat\ areas} = 0.3 - 0.6$
  - o $f_{slopes} = 0.05 – 0.2$

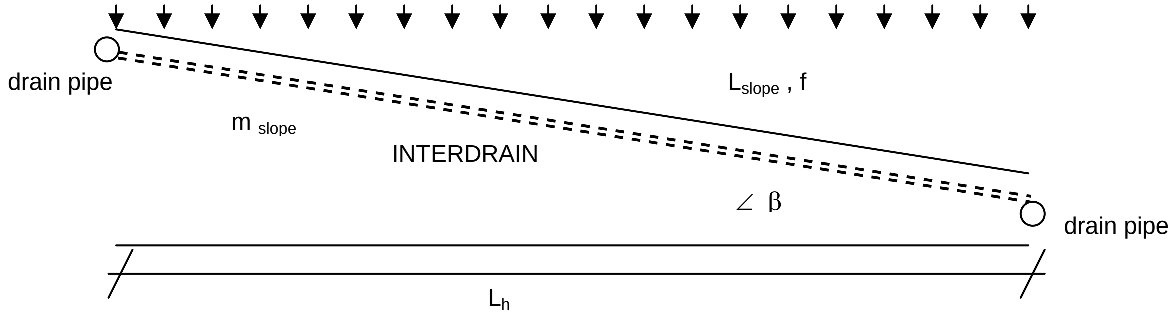

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Figure 2. Diagram of the cap. Source: INTERMAS NETS S.A.

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5.3. DESIGN METHOD

The INTERDRAIN drainage geocomposite must have a drainage capacity ($q_{\text{INTERDRAIN}}$) greater than the maximum amount of water that could infiltrate along the whole slope ($q_{\text{infiltration}}$):

- $q_{\text{INTERDRAIN}} > q_{\text{infiltration}}$
- $q_{\text{infiltration}} = f \cdot L_h \cdot P_{\text{rain}} \cdot \cos\beta$
- $q_{\text{INTERDRAIN}} > f \cdot L_h \cdot P_{\text{rain}} \cdot \cos\beta$

6. EXAMPLE OF THE SECOND METHOD

6.1. HYPOTHESES

The landfill slopes will have the following characteristics:

- L = Length of the slope = 15 m
- β = Slope angle. = 24º
- h = Height of the covering soil

The rainfall measurement will be:

- $P_{T = 2 \text{ years}}$ = 75 mm/h (T= 2 years)
- $P_{T = 25 \text{ years}}$ = 120 mm/h (T= 25 years)

The infiltration coefficients will be:

- $f_{\text{first year}} = 0.4$
- $f_{\text{definitive cap}} = 0.1$

6.2. CALCULATING THE MAXIMUM QUANTITY OF WATER INTERDRAIN MUST DRAIN OFF

The water the INTERDRAIN drainage geocomposite must drain will be:

$q_{\text{infiltration (T = 2 years)}} = P_{T = 2 \text{ years}} \cdot L_h \cdot \cos(\beta) \cdot f_{\text{first year}}$
$q_{\text{infiltration (T = 25 years)}} = P_{T = 25 \text{ years}} \cdot L_h \cdot \cos(\beta) \cdot f_{\text{final cap}}$

$q_{\text{INTERDRAIN short term}}$ > 75 l/m2·h · 15m · cos (24º) · cos (24º) · 0.4 = 375.5 l/m·h = **0.10 l/m·s**
$q_{\text{INTERDRAIN long term}}$ > 120 l/m2·h · 15m · cos (24º) · cos (24º) · 0.1 = 150.2 l/m·h = **0.04 l/m·s**

6.3. SHORT-TERM DRAINAGE CAPACITY OF INTERDRAIN

From table 1 we choose the row corresponding to i=0.4 and we obtain the drainage capacities of the different INTERDRAIN drainage geocomposites:

gradient -	slope angle º	pressure kPa	$q_{\text{GMG 412}}$ l/s/m	$q_{\text{GMG 512}}$ l/s/m	$q_{\text{GLG 612}}$ l/s/m	$q_{\text{GM 412}}$ l/s/m	$q_{\text{GM 512}}$ l/s/m	$q_{\text{GL 612}}$ l/s/m
0.4	23.58	20	0.31	0.60	0.82	0.74	0.84	1.15

Table 4. Short-term drainage capacity of INTERDRAIN submitted to i=0.4 and σ=20kPa. Source: INTERMAS NETS S.A.

6.4. CALCULATING THE SHORT TERM SAFETY FACTOR (1 YEAR)

The short-term drainage capacity and the quantity of rainwater in situation A) are used

- **$FS_{\text{GMG 412}}$** = $q_{\text{GMG 412}} / q_{\text{IN}}$ = 0.31 / 0.10 **= 3.1**
- **$FS_{\text{GMG 512}}$ =** $q_{\text{GMG 512}} / q_{\text{IN}}$ = 0.60 / 0.10 **= 6.0**
- **$FS_{\text{GLG 612}}$ =** $q_{\text{GLG 612}} / q_{\text{IN}}$ = 0.82 / 0.10 **= 8.2**

The whole INTERDRAIN range ensures the correct drainage.
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6.5. LONG-TERM DRAINAGE CAPACITY OF INTERDRAIN

$RF_{in} \cdot RF_{cc} \cdot RF_{bc} \cdot RF_{cr} = 1.1 \cdot 1.19 \cdot 1.1 \cdot 2 = 2.88$

gradient -	slope angle º	Pressure kPa	$q_{GMG\ 412}$ l/s/m	$q_{GMG\ 512}$ l/s/m	$q_{GLG\ 612}$ l/s/m	$q_{GM\ 412}$ l/s/m	$q_{GM\ 512}$ l/s/m	$q_{GL\ 612}$ l/s/m
0.4	23.58	20	0.11	0.21	0.28	0.26	0.29	0.40

Table 5. Long-term drainage capacity of INTERDRAIN submitted to i=0.4 and σ=20kPa. Source: INTERMAS NETS S.A.

6.6. CALCULATING THE LONG-TERM SAFETY FACTOR (100 YEARS)

The long-term drainage capacity of INTERDRAIN and the quantity of rain water infiltrated in situation B are used.

- $FS_{GMG\ 412} = q_{GMG\ 412} / q_{IN} = 0.11 / 0.04 = \mathbf{2.7}$
- $FS_{GMG\ 512} = q_{GMG\ 512} / q_{IN} = 0.21 / 0.04 = \mathbf{5.2}$
- $FS_{GLG\ 612} = q_{GLG\ 612} / q_{IN} = 0.28 / 0.04 = \mathbf{7.0}$

The whole INTERDRAIN range ensures the correct drainage.

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AASHTO (1996)	Standard Specification for Geotextiles, Designation: M288-96. *American Association of State Transportation and Highway Officials, Washington, D.C.*
ENV 1897	Geotextiles y productos relacionados. Determinación de las propiedades de fluencia en la compresión.
ENV 12225	Geotextiles y productos relacionados. Método para determinar la resistencia microbiológica mediante un ensayo de enterramiento en el suelo.
UNE-EN ISO 12958	Geotextiles y productos relacionados. Determinación de la capacidad de flujo en su plano.
ISO/TR 12960	Geotextiles y productos relacionados. Método de ensayo de protección para la determinación de la resistencia a los líquidos.
UNE CR ISO 13434	Guía para la durabilidad de los geotextiles y los productos relacionados con geotextiles

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ASTM D1621-00	Standard Test Method for Compressive Properties of Rigid Cellular Plastics
www.landfillsdesign.com	Website dedicated to dimensioning with geosynthetics in landfills.

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APPENDIX 1. CALCULATING RF_{CR} FOR INTERDRAIN DRAINAGE GEOCOMPOSITES

RF_{CR} is specific for each product. INTERDRAIN geocomposites are made up of a geonet of high-density polyethylene with great resistance to compression and excellent long-term behaviour, so **RF_{CR}** will be lower that for other products made in other materials and configurations.

Recent studies carried out by Giraud et a. (2000) show a relationship between the reduction in drainage capacity because of the creep effect and the thickness of the geonet (just the geonet, not the geocomposite).

The relationship is as follows:

$$RF_{CR} = \left[\frac{(t_{CO} / t_{original}) - (1 - n_{original})}{(t_{CR} / t_{original}) - (1 - n_{original})}\right]^3$$

Giraud et al. (2000)

Where:
- $t_{original}$: thickness of the geonet without being submitted to any load (cm).
- t_{co}: thickness of the geonet measured seconds after receiving high pressure (cm).
- t_{cr} : long-term thickness of the geonet, after 100 years (cm).
- $n_{.original}$: initial porosity without the product being submitted to any load (-).

Given that in the transmissivity test (according to the ISO 12958 standard) the sample is allowed to stabilize for about 15 minutes after the test begins, it is logical to use:

- t_{co}: thickness of the geonet measured 15 minutes after receiving the given pressure (cm).

The porosity is defined as:

$$n_{original} = 1 - \frac{\mu}{\rho t_{original}}$$

Where:
- μ : mass per unit of the area of the geonet (g/cm^2).
- ρ : density of the geonet polymer (g/cm^3).

Using the ENV 1897 (compressive creep properties) test, we obtain the long-term behaviour of the drainage geonet.

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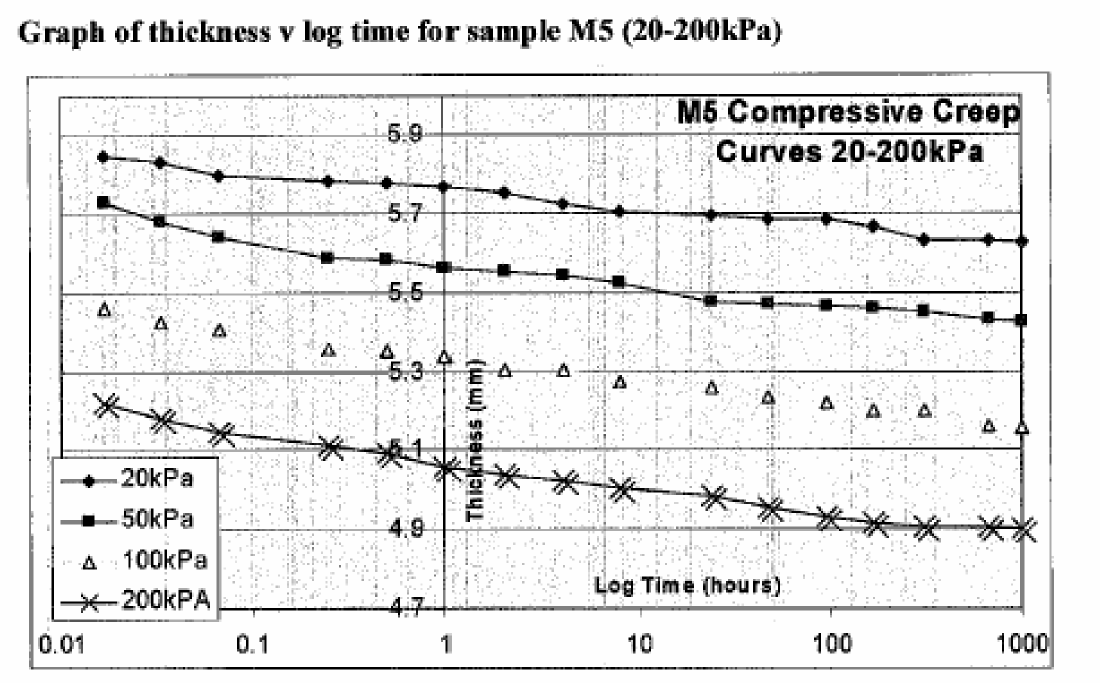

Reduction in thickness of the INTERDRAIN M5 drainage geonet over time.
Source: GEOTRAC Laboratory.

Geocomposites with drainage INTERDRAIN geonets have a thickness changing in line with the logarithm of time.

Based on the ENV 1897 test, we can estimate what the thickness will be after 100 years.

The estimate gives a $t_{CR=100\ years}$ = 5.5 (mm) (thickness at 20 kPa after 1,000,000 hours = 114 years)

Moreover:

- $t_{original}$ = 5.917 (mm) (thickness at 2 kPa)
- $t_{co=15m}$ = 5.784 (mm) (thickness at 20 kPa after 15 minutes)
- $\rho = 0{,}94$ g/cm^3 (Density of the polymer)
- μ = 650 g/m^2 = 0.065 g/cm2 (mass of the geonet).

We obtain:

$$n_{original} = 1 - \frac{0{,}065}{0{,}94 \cdot 0{,}5917} = 0.883$$

$$\mathbf{RFcr} = \left[\frac{(5{,}784/5{,}917) - (1 - 0{,}883)}{(5{,}500/5{,}917) - (1 - 0{,}883}\right]^3 = \mathbf{1.19}$$

This calculation is the result of our revised and corrected knowledge. INTERMAS refuses to accept any responsibility deriving from its use in works schemes and provides it purely for information purposes.