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DIMENSIONING INTERDRAIN FOR CAPTURING AND DRAINING BIOGAS GENERATED IN A LANDFILL

STUDY CONTENTS:

1. INTRODUCTION

The pressure of gas generated in the capping layers of a landfill significantly reduces the friction between the geomembrane and the drainage layer, which can affect the stability of the cap. This technical study offers a method for dimensioning the INTERDRAIN drainage compound, which has transmissivity greater than that of gases, thereby preventing the saturation of the draining layer.

A large number of stability failures in caps occurring over the last decade have been attributed to the layer's inadequate biogas drainage capacity. According to recent studies based on the theory of intrinsic permeability, the transmissivity ratio of the gas is approx.10 times less than the hydraulic transmissivity ratio in any porous medium. In the past, it was believed that this relationship was inverse, which led to an underestimate of the capacity for transmission of the gas in the drainage layer.

This aim of this technical study is to offer a design method for INTERDRAIN drainage geocomposites as systems for capturing and draining the biogas generated in landfill. An example will be used to make it easier to understand the study.

2. EXAMPLE USED IN THE STUDY

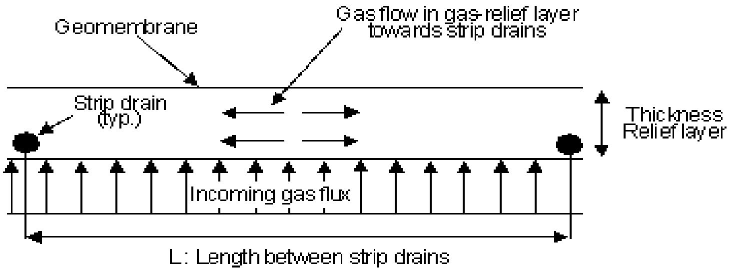

Diagram 1. Diagram of a biogas drainage system in a cap.
Source: www.landfilldesign.com

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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A landfill with the following characteristics will be considered:

- $H_{avg\ waste}$: Average height of the waste = 20 m
- δ_{waste}: Waste density = 1000 kg/m^3
- r_G= Gas generation index = 6.24·10^{-3} m.^{3}/kg/year (value recommended by *Thiel*)
- u_{gmax}: Maximum pressure exerted by the gas on the drainage geocomposite = 2 kPa (usually between 1 kPa and 3 kPa)
- γ_{LFG}: Specific weight of the gas = 0.01157 kN/m.^{3} (see table 1)
- L: Distance between gas drainage lines = 60 m
- Geometry of the cap: The landfill cap will have slopes of 24º and a flat area with a slope of 5%.

R.S. Thiel recommends a gas generation index (r_G) at the end of the life of the cell of 6.24·10^{-3} m^3/kg/year. This value is the result of experience of solid waste landfills in the United States.

The expected composition of the gas generated by the waste in the landfill, together with the densities, specific weights and dynamic and kinematic viscosities can be found in the following table:

Gas	%	Density ρ (kg/m^3)	Specific weight γ (N/m^3)	Dynamic viscosity μ (N-s/m^2)	Kinematic viscosity υ (m^2/s)
Water	-	1000	9800	1.01E-03	1.01E-06
CH_4	50	0.666	6.54	1.10E-05	1.65E-05
CO_2	40	1.83	17.9	1.50E-05	8.21E-06
N_2	8	1.16	11.38	1.77E-05	1.52E-05
H_2	1	-	-	-	-
Others	1	-	-	-	-
LFG (Gas)	100%	1.18	11.57	1.32E-05	1.30E-05

Table 1. Expected composition of the gas generated in a landfill. Source: www.landfilldesign.com

3. CALCULATION METHOD

The method proposed by INTERMAS NETS S.A. consists of:

- Estimating the flow of gases generated in the landfill (section 4)
- Calculating the minimum transmissivity required for the drainage geocomposite (section 5)
- Gas transmissivity-hydraulic transmissivity equivalence (section 6).
- Calculating the short-term drainage capacity of INTERDRAIN geocomposites (section 7)
- Calculating the long-term drainage capacity of INTERDRAIN geocomposites (section 8)
- Calculating the long-term transmissivity of INTERDRAIN drainage geocomposites and calculation of the safety factors (section 9).

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4. GAS GENERATION FLOW

The formula recommended in the document "Design of Lateral Drainage Systems for Landfills (2000)" will be used

The flow of gases from a landfill can be estimated using the following formula:

$$\Phi_{LFG} = r_g \cdot H_{avg\ waste} \cdot \delta_{waste}$$

Where:

- Φ_{LFG}: Total flow of gas generated ($m^3/s/m^2$)
- r_g: Gas generation index = $6.24 \cdot 10^{-3}\ m^3/kg/year$
- $H_{avg\ waste}$: Average height of the waste = 20 m
- δ_{waste}: Waste density = 1000 kg/m^3

We obtain a total flow of:

$$\Phi_{LFG} = r_g \cdot H_{avg\ waste} \cdot \delta_{waste} = \frac{6{,}24 \cdot 10^{-3} \cdot 20 \cdot 1000}{365 \cdot 24 \cdot 60 \cdot 60} = 3.96 \cdot 10^{-6}\ m^3/s/m^2$$

5. MINIMUM TRANSMISSIVITY REQUIRED FROM THE GAS DRAINAGE GEOCOMPOSITE

The minimum transmissivity required from a gas drainage geocomposite can be calculated from *Thiel's* expression:

$$T_{required\ LFG} = \frac{\Phi_{LFG} \cdot \gamma_{LFG}}{u_{gmax}} \cdot \left[\frac{L^2}{8}\right]$$ *(Thiel, 1999)*

Where:

- $T_{required\ LFG}$: Transmissivity required from the gas drainage geocomposite (m^2/s)
- u_{gmax} : Maximum pressure exerted by the gas on the drainage geocomposite = 2kPa
- Φ_{LFG} : Total gas flow generated = $3.96 \cdot 10^{-6}\ m^3/s/m^2$
- γ_{LFG} : Specific weight of the gas = $0.01157\ kN/m^3$
- L: Distance between gas drainage lines = 60m

The minimum transmissivity required for the gas drainage geocomposite, considering the above values is:

$$T_{required\ LFG} = \frac{\Phi_{LFG} \cdot \gamma_{LFG}}{u_{gmax}} \cdot \left[\frac{L^2}{8}\right] = \frac{3{,}96 \cdot 10^{-6} \cdot 0{,}01157}{2} \cdot \left[\frac{60^2}{8}\right] = 1.03 \cdot 10^{-5}\ m^2/s$$

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6. GAS TRANSMISSIVITY-HYDRAULIC TRANSMISSIVITY EQUIVALENCE

As we do not have transmissivity values for the drainage geocomposites in gas circulation conditions, the following equivalence will be used:

$$T_{H_2O} = \frac{\mu_{LFG} \cdot \gamma_{H_2O}}{\mu_{H_2O} \cdot \gamma_{LFG}} \cdot T_{LFG}$$

The equivalent hydraulic transmissivity is:

$$T_{H_2O} = \frac{1{,}32 \cdot 10^{-5} \cdot 9800}{1{,}01 \cdot 10^{-3} \cdot 11{,}57} \cdot 1.03 \cdot 10^{-5} = 11.07 \cdot 1.03 \cdot 10^{-5} = 0.11 \cdot 10^{-3}\ m^2/s = 0.11 l/m \cdot s$$

INTERDRAIN drainage geocomposites must have a long-term transmissivity greater than:

$T_{INTERDRAIN\ long\text{-}term}$ > 0.11 l/m·s

7. SHORT-TERM DRAINAGE CAPACITY OF INTERDRAIN

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

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 2. Short-term drainage capacity of INTERDRAIN drainage geocomposites submitted to20 kPa (landfill cap) and at different gradients. Source: INTERMAS NETS S.A.

The calculation of the drainage capacity of INTERDRAIN at 20 kPa and at different gradients can be seen in the study "Dimensioning the INTERDRAIN geocomposite for draining off rainwater infiltrated into a landfill cap" (INTERMAS NETS S.A., 2005).

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Selecting the corresponding column from table 1 and with i=0.05, we obtain:

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
0.05	2.87	20	0.09	0.16	0.27	0.21	0.23	0.36

Table 3. Short-term drainage capacity of INTERDRAIN submitted to i=0.05 and σ=20kPa.
Source: INTERMAS NETS S.A.

Selecting the corresponding column from table 1 and with i=0.4, we obtain:

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	0.31	0.60	0.82	0.74	0.84	1.15

Table 4. Short-term drainage capacity of INTERDRAIN submitted to i=0.05 and σ=20kPa.
Source: INTERMAS NETS S.A.

8. 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 biogas are the following (www.landfilldesign.com):

- RF_{in} = 1.0 – 1.2
- RF_{CR} = 1.19 (case of INTERDRAIN geocomposites)
- RF_{cc} = 1.0 – 1.2
- RF_{bc} = 1.2 – 1.5

Considering average reduction factors, we obtain:

$RF_{in} \cdot RF_{cc} \cdot RF_{bc} \cdot RF_{cr} = 1.1 \cdot 1.19 \cdot 1.1 \cdot 1.4 = 2$

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- For i=0.05, we obtain:

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
0.05	2.87	20	0.04	0.08	0.13	0.10	0.11	0.18

Table 5. Long-term drainage capacity of INTERDRAIN submitted to i=0.05 and σ=20 kPa.
Source: INTERMAS NETS S.A.

- For i=0.4, we obtain:

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	0.15	0.30	0.41	0.36	0.42	0.57

Table 6. Long-term drainage capacity of INTERDRAIN submitted to i=0.05 and σ=20 kPa.
Source: INTERMAS NETS S.A.

9. CALCULATING THE LONG-TERM TRANSMISSIVITY OF INTERDRAIN AND CALCULATING THE SAFETY FACTOR

The relationship between transmissivity (T) and drainage capacity (q) is:

$q_{INTERDRAIN}\ (m^2/s) = T_{INTERDRAIN}\ (m^2/s) \cdot i$

Where:
- i = hydraulic gradient

- For i=0.05, we obtain:

gradient -	slope angle º	pressure kPa	$T_{GMG\ 412}$ l/s/m	$T_{GMG\ 512}$ l/s/m	$T_{GLG\ 612}$ l/s/m	$T_{GM\ 412}$ l/s/m	$T_{GM\ 512}$ l/s/m	$T_{GL\ 612}$ l/s/m
0.05	2.87	20	0.80	1.60	2.60	2.00	2.20	3.60

Table 5. Long-term transmissivity of INTERDRAIN submitted to i=0.05 and σ=20kPa.
Source: INTERMAS NETS S.A.

The whole INTERDRAIN range has a long-term transmissivity greater than 0.11l/m·s, with safety factors ranging from 7.2 (GMG 412) to 32.7 (GL 612).

- For i=0.4, we obtain:

gradient -	slope angle º	Pressure kPa	$T_{GMG\ 412}$ l/s/m	$T_{GMG\ 512}$ l/s/m	$T_{GLG\ 612}$ l/s/m	$T_{GM\ 412}$ l/s/m	$T_{GM\ 512}$ l/s/m	$T_{GL\ 612}$ l/s/m
0.4	23.58	20	0.35	0.75	1.02	0.90	1.05	1.42

Table 6. Long-term transmissivity of INTERDRAIN submitted to i=0.05 and σ=20kPa.
Source: INTERMAS NETS S.A.

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The whole INTERDRAIN range has a long-term transmissivity greater than 0.11 l/m·s, with safety factors ranging from 3.1 (GMG 412) to 12.9 (GL 612).

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