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DESIGN CRITERIA FOR GEOSYNTHETIC DRAINAGE SYSTEM IN WASTE DISPOSAL

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SUMMARY: the paper deals with the use of geonets to solve drainage problems in waste disposals, and it suggests some design criteria to provide engineers with methods to solve the following practical situations: drainage of leachate on the slopes and on the bottom; drainage of leakage under the primary geomembrane; drainage of capping; drainage of liquids and gases between the soil and the lower waterproofing layer. Finally, some general design details are provided.

1. INTRODUCTION

The present century is marked by a dramatic increase of the total World population, tending to be progressively concentrated into large, urban and industrial areas; as a consequence, land disposal of municipal or industrial, hazardous wastes (in the philosophy of "concentrating and containing") has become an ever more common practice, giving origin to serious environmental problems. In addition, the average living standards are growing in most developed countries, so further increasing waste production and introducing a supplementary factor of environmental hazard. Despite of the new concepts of "recycling", large amounts of wastes cannot be, economically or technically, converted; therefore, the Humanity will have to solve waste disposal problems for many years again.

The environmental hazards related to waste disposal include (Morgenstern, 1985):

a) hazards associated to the movement of solids (stability problems and failures of cut-slopes, earth dumps, coaltips, landfills, and tailings dams);

b) hazards associated to toxic fluid storage and flow (brine ponds, sewage lagoons, hazardous waste containment, pollution of surface and ground water).

In all cases, the necessity to ensure the stability of waste landfills and to protect the environment from pollution requires that drainage systems (for surface and ground water, leachate, and biogas) be properly designed and carefully installed.

For such applications, the use of geosynthetics has been increasing during the last 20 years, and it's still increasing today. With respect to traditional liners and drains, made with natural soils, geosynthetics present some technical and economical advantages, as in the following:

- reduced thickness, allowing to obtain an additional volume for disposing wastes in the same site;
- constancy of physical, hydraulic and mechanical properties, and related quality control;
- easiness and reduced times of putting-in-place.

Sanitary landfills for urban garbage or other solid wastes need technical solutions for many hydraulic problems, such as:

- the necessity of leachate retention at the bottom of disposal sites;
- for depression landfills, the underliner drainage of the slopes and bottom of the depression;
- the drainage of leachate losses through the liner (both natural and synthetic);
- for landfills of toxic chemical wastes, equipped with a double bottom liner, the necessity of a control drainage between the two liners;
- the necessity of reducing excess pore pressures due to leachate build up within the waste tip;
- the necessity of controlling and reducing biogas accumulation within the waste tip;
- the necessity of sealing the top of the landfill, in order to control rain water infiltration and to avoid uncontrolled gas escaping.

An example of sanitary landfill equipped with geosynthetics is schematically shown in Fig. 1.

Synthetic materials perform different hydraulic functions (filtration and drainage, or moisture barrier), and also mechanical ones (separation and reinforcement); they include the following basic types (modified from Koerner, 1986):

a) geomembranes ("impervious" liners, made of sheets of rubber or plastic material, used as liquid or gas barriers);
b) geotextiles (two-dimensional fabrics and non-wovens, made of synthetic fibres matted together by standard weaving machinery or in a random manner, also by knitting, used for drainage, filtration, separation and also for reinforcement);
c) geogrids (two-dimensional, geometrically defined, high tensile resistant structures, composed of extruded and stretched plastic sheeting, with a

regular distribution of elliptic or rectangular openings, used for reinforcement of soil;

d) geonets (three-dimensional, geometrically defined, bulky structures, composed of thermally or mechanically bonded synthetic filaments, used mainly for drainage and transport of liquids or gases); some types (made of profiled rigid plastic sheeting or of synthetic mats of randomly distributed filaments) are also called geospacers (Hoekstra & Berkhout, 1986);
e) geocomposites (three-dimensional combinations of two or more basic types, such geotextile and geonet, geotextile and geo-membrane, geonet and geomembrane, or others), used for various applications in waste landfill and other fields of civil engineering.

Designing geosynthetic drainage systems can present peculiar difficulties and uncertainties if these hydraulic structures are put in contact with wastes instead of natural soils. For instance, in many applications geotextiles are not supposed to come into contact with leachate, and interactions can be occasionally originated from defective installation, or from long-term deterioration of the geomembrane; in other cases, a geotextile is used as filter and drainage for leachate collection systems, and comes directly into contact with leachate since the beginning of landfilling operations, so it should be properly selected and designed for such working conditions (Cancelli & Cazzuffi, 1987). Supplementary problems, due to previously unforeseen leachates, are given by landfills in which chemical wastes are admixed with domestic garbage.

Some general criteria for designing with geosynthetics are well known in the international literature (see e.g. Giroud, 1984; Van Zanten, 1986; Koerner, 1986). However, the increasing use of geosynthetics (including geonets and geonet based geocomposites) requires to discuss the theoretical approach to the behaviour of geosynthetic drainage systems in waste landfills and to draw some design criteria for most practical applications.

2. THEORY

2.1 Collection and drainage of leachate

2.1.1 Calculation of input flow.

The quantity of liquid reaching the primary synthetic drainage system depends mainly on local conditions of rainfall, type of soil cover, actual situation of the waste disposal (in use or after capping).

All the possible situations can be reduced to the scheme presented in Fig.2.

The rainfall per unit area is given by:

$$q_r = P / A \qquad (1)$$

with: P = rainfall [m^3/s];
A = horizontal area [m^2];
q_r = rainfall per unit horizontal area [$m^3/s/m^2$].

Since the actual surface is sloping, the effective area is:

$$q_f = P / A_1 = P / (A / \cos\alpha) = P \cdot \cos\alpha \, / \, A = q_r \cdot \cos\alpha \qquad (2)$$

where: q_f = rainfall per unit area on slope [$m^3/s/m^2$]

Not all the rainfall reaches the drainage system, since a part of it becomes runoff; therefore the input rainfall is given by:

$$q_d = q_f \cdot f = q_r \cdot \cos\alpha \cdot f \qquad (3)$$

where: f = coefficient of infiltration of the cover material;
q_d = rainfall, per unit area on slope, entering the drainage system [$m^3/s/m^2$].

The input rainfall collects along the slope to give the total input flow:

$$Q_d = q_d \cdot L \cdot 1 = q_d \cdot L \qquad (4)$$

with: L = length of the slope [m];
Q_d = input flow [m^3/s].

There are two different situations to be taken into account:
a) waste disposal in use;
b) waste disposal after capping.

2.1.1.1 Waste disposal in use

In this situation the most severe conditions for the drainage system occur during intense rainfalls: therefore q_r corresponds now to the rainfall intensity j expressed as [m/s].

According to the principles of hydrology it is possible to compute j by the equation of the rainfall possibility relative to the hydrologic region of the waste disposal:

$$h_r = a \cdot t^n \tag{5}$$

Therefore:

$$j = h_r / t = a \cdot t^{n-1} \tag{6}$$

with: h_r = height of rainfall [mm];
t = duration of the rainfall [h];
j = rainfall intensity [mm/h].

Finally to pass from j to q_r, expressed as [$m^3/s/m^2$=m/s], the following equation applies:

$$q = j \cdot 2.777 \cdot 10^{-7} \tag{7}$$

Equation (4) becomes now:

$$Q = 2.777 \cdot 10^{-7} \cdot a \cdot t^{n-1} \cdot \cos\alpha \cdot f \tag{8}$$

For the coefficient of infiltration f, it is possible to use the following values :

f = 0.2÷0.35	for drainage system covered with soil or wastes;
f = 1.0	for no coverage of the drainage system.

The value of f in case of soil/waste cover is extrapolated from measurements taken in different waste disposals, as shown in Fig.3 (Wiemer, 1987).
The coefficients a and n of the rainfall possibility curve can change considerably from zone to zone. As an example, for the area of the city of Milan, Italy, the values are :

a = 53.46; n = 0.407 if t = 0.7 hours;
a = 50.06; n = 0.222 if t > 0.7 hours.

These values were calculated for a "return time" of 10 years.
The most part of the Codes actually available for waste disposal (like in U.S.A. and Italy) requires that the drainage system must be designed for a rainfall having a "return time" of 10 years.
It appears reasonable to use in eq.(8) a duration of rainfall

t = 0.5 ÷ 1.0 hour.

2.1.1.2 Waste disposal after capping

In this situation the leachate originates from the water contained in the waste materials, which is released during the mineralization process.

It is possible to estimate the following quantities [Andretta et Al., 1988] :

Q_p=total quantity of released leachate= 6 m^3/m^2 = 6m
t_p= time to release all the leachate = 10 years = 3.1 x 10^8 sec

Then, in this case :

$$q_r = Q_p / t_p = 1.9 \cdot 10^{-8} \tag{9}$$

This value of q_r appears to be far less than the value obtainable from eq. (7): therefore the situation of waste disposal in use is more critical than the situation after capping for designing the drainage system.
The design of the geosynthetics drainage system on slopes and bottom of the waste disposal should therefore be done for the situation of waste disposal in use.

2.1.2 Critical input flow

2.1.2.1. Waste disposal in use

With reference to Fig. 4, the input flows Q_b and Q_c in points B and C are critical in the situation of waste disposal in use.
Therefore the input flow to design the geosynthetics drainage system on the slopes is given by :

$$Q_b = q_r \cdot f_1 \cdot cos\alpha_1 \cdot L_1 + q_r \cdot f_2 \cdot cos\alpha_1 \cdot L_2 \tag{10}$$

with: α_1 = angle of side slopes [deg];
L_1 = length of slope over the waste mass [m];
L_2 = length of slope under the waste mass [m];
f_1 = coefficient of infiltration on AF (see Fig. 4) ≈ 1.0;
f_2 = coefficient of infiltration on FB (see Fig. 4) ≈ 0.2 ÷ 0.3.

The input flow to design the drainage system on the bottom is:

$$\begin{aligned} Q_c &= Q_b + q_r \cdot f_3 \cdot \cos\alpha_2 \cdot L_3 = \\ &= q_r \cdot \left(f_1 \cdot L_1 \cdot \cos\alpha_1 + f_2 \cdot L_2 \cdot \cos\alpha_1 + f_3 \cdot L_3 \cdot \cos\alpha_2 \right) \end{aligned} \tag{11}$$

with: L = distance between the top of the slope and the main trench or well [m];
α_2= inclination of the bottom [deg];
f_3 = coefficient of infiltration on BC (see fig.3) = 0.2 ÷ 0.3.

In general, to take into account a situation with different lengths Li, different inclinations α_j and different coefficient of infiltration fi, the following equation can be used:

$$Q_c = q_r \cdot \sum_{ij} f_i \cdot L_j \cdot \cos\alpha_j \qquad \text{(11 bis).}$$

2.1.2.2. Waste disposal after capping

With reference to Fig.5, the input flows Q_e and Q_a are critical for the design of the drainage system between the capping waterproofing layer and the soil cover. They are given by:

$$Q_e = q_r \cdot f_4 \cdot L_4 \cdot \cos\alpha_3 \qquad (12)$$

$$Q_a = Q_e + q_r \cdot f_4 \cdot L_5 \cdot \cos\alpha_4 = q_r \cdot f_4 \cdot \left(L_4 \cdot \cos\alpha_3 + L_5 \cdot \cos\alpha_4\right) \qquad (13)$$

with: α_3 = inclination in ED (see fig.4) [deg]
α_4 = inclination in AE (see fig.4) [deg]
L_4 = distance between points E and D (see fig.4)
L_5 = distance between points A and E (see fig.4)
f_4 = coefficient of infiltration of the soil cover.

For the coefficient f_4 the following empirical values are generally assumed in common practice:

f_4 = 0.8 for uniformly grassed soil cover;
f_4 = 0.2 for bare soil cover.

Therefore, since in general the soil cover will not be permanently covered with grass, an average value can be constantly assumed for f:

f_4 = 0.5

2.2 Drainage of leakage

Leaks of leachate from the primary waterproofing liner can occur fundamentally for two reasons: defects in seams of the geomembrane or damages to the liner during placement and compaction of waste materials.

Both cases are extremely difficult to predict and therefore some simplifying hypotheses are necessary to evaluate the leakage flow rate.
With reference to Fig. 6, the first hypothesis is that the leachate drainage system is designed in such a way to maintain the hydraulic head on the bottom of the waste disposal under a maximum limit value; according to U.S.A. regulations [E.P.A.,1985], the maximum hydraulic head allowed on the bottom is :

$$h_{max} = 0.30 \text{ m} \tag{14}$$

The second hypothesis is that the holes produced in the primary liner have an average size, as measured in different practical situations in many waste disposal [Bonaparte et Al., 1987], given by:

$$A_{hole} = 1 \text{ cm}^2 = 0.0001 \text{ m}^2 \tag{15}$$

The third hypothesis is that the liquid flows through the holes according to Bernoulli's law for free flow through orifices; the average speed of the flow through the holes is then:

$$v = C \cdot \sqrt{2g \cdot h_{max}} \tag{16}$$

with : C = coefficient of flow through orifices = 0.60 (sharp edged holes).

The average flow rate through a single hole is then:

$$Q_{hole} = v \cdot A_{hole} = C \cdot A_{hole} \cdot \sqrt{2g \cdot h_{max}} \tag{17}$$

with: Q_{hole} = flow rate through a single hole [m^3/s].

Q_{hole} from eq.(17) is an upper boundary value, since if there is liquid pressure under the hole, the flow rate through the hole decreases: therefore Q_{hole} is the flow rate to design the leakage drainage system.

In order to design the well to collect all the leakage from all the holes in the primary liner, the following hypothesis is needed : the average frequency is of 1 hole every 4.000 m^2 of primary liner, as measured in different waste disposal [Bonaparte at Al, 1987; Faure, 1984; Giroud-Fluet, 1986; Kastman, 1984].

The total flow rate arriving to the collector well is then:

$$Q_t = v \cdot A_{hole} \cdot S \cdot F_{hole} \tag{18}$$

with : Q_t = total leakage flow rate [m^3/s]
S = total surface of primary liner (side slopes and bottom) [m]
F_{hole}= average frequency of holes = 1/4000 [m^{-2}].

2.3 Drainage between soil and bottom liner

With reference to Fig.7, it is not possible in this case to define a general method to evaluate the flow Q_t, reaching the drainage system between the soil and the bottom liner. In general, if the water table is some meters under the bottom of the waste disposal, then Q_f is due only to humidity and capillarity and it can be assumed equal to zero. In this case between the soil and the bottom liner only a layer to protect the bottom liner is needed: therefore the protective geosynthetic (geonets or nonwoven geotextiles) should be selected based on mechanical properties like compression and puncture resistance. On the contrary, if there is a small water flow outcoming on the side slopes or at the bottom, it is needed to evaluate the specific flow rate Q_f [$m^3/s/m$] case by case.

2.4 Flow rate and transmissivity of the geonets

In order to design a geosynthetic drainage system, it is needed to know the discharge which every type of geonets can carry, under specified conditions of applied pressure and hydraulic gradient.
The hydraulic gradient i [-] is defined as:

$$i = \frac{\delta h}{L} \qquad (19)$$

with: δh = loss of hydraulic head of the fluid flowing in the geonet [m];
L = distance between two points along the average direction of flow in the geonet [m].

The discharge capacity can be given in terms of transmissivity, defined as the discharge per unit width of the geonet and per unit of hydraulic gradient; or better in terms of specific flow-rate, defined as the discharge per unit width in the geonet, under a specified hydraulic gradient.
Under the hypothesis that the fluid flow is laminar and on the base of the Darcy's law, transmissivity and specific flow rate are given by:

$$\Theta = (q / B) / i \qquad (20)$$

$$Q = (q / B) \qquad (21)$$

with : Θ = transmissivity [$m^3/s/m = m^2/s$];
Q = specific flow-rate [$m^3/s/m = m^2/s$];
q = discharge [m^3/s];
B = width of the geonet [m].

To authors' opinion, the specific flow-rate is more suitable for practical use.

The specific flow-rate of geonets can be measured with an apparatus similar to the one originally used by Darcy to measure the permeability of sands: as shown in Fig.8, it consists of two water reservoirs which allow to maintain a constant head and a central housing for the geosynthetic specimen, upon which a constant predefined pressure is applied by means of a rigid plate, and of a system for measuring the steady state flow (Cancelli at Al, 1987).

The results of these tests are usually presented in form of diagrams (see Fig.9), giving the specific flow-rate Q [m^2/s] versus the applied pressure σ [kPa], with different curves having the hydraulic gradient i as parameter.
The tests are usually performed in laboratory using water at 20°C temperature.

It is possible to calculate the specific flow-rate for another temperature with the equation :

$$Q_{20} = Q_T \cdot \left(\frac{\eta_{20}}{\eta_T} \right) \qquad (22)$$

with: Q_{20} , Q_T= specific flow-rate at 20°C and T °C;
η_{20}, η_T = viscosity of water at 20°C and T °C.

2.5 <u>Selection of the geonet</u>

The required specific flow-rate for the geonet is :

$$Q_{req} = Q_{in} \cdot FS \qquad (23)$$

where: Q_{req}= required specific flow-rate [m^2/s];
Q_{in} = input flow-rate [m^2/s];
FS = Factor of Safety.

In order to select the geonet for a specific project, it is needed to evaluate the pressure applied to the geonet and the hydraulic gradient i under which the fluid flows in the geonet. At this point, it is possible to enter the diagrams of different geonets: as shown in Fig.10, if the condition is (i_1, σ_1) the geonet is unacceptable, since $Q_1<Q_{req}$; if the condition is (i_2, σ_2) the geonet is acceptable, since $Q_2>Q_{req}$.

If the value of i is different from the values of the diagram, it is possible to evaluate the specific flow-rate for the actual hydraulic gradient i by the experimental formula (Rimoldi, 1989):

$$Q_{i2} = Q_{i1} \cdot \sqrt{\frac{i_2}{i_1}} \qquad (24)$$

with: Q_{i1}= specific flow-rate from the diagram [m^2/s];
Q_{i2}= specific flow-rate for the i_2 gradient [m^2/s];
i_1 = the hydraulic gradient on the diagram of the geonet, immediately above the actual hydraulic gradient;
i_2 = actual hydraulic gradient.

As an example, if the bottom has an inclination α_2 = 1.5° and the minimum value on the diagram of the geonet is i_1=0.25, then:

i_2 = 0.020 (see eq. 25)

and

$$Q_{i=0.020} = Q_{i=0.25} \cdot \sqrt{\frac{0.020}{0.25}} = 0.28 \cdot Q_{i=0.25}$$

3. PRACTICAL SITUATIONS

3.1 Primary drainage system for collecting leachate

With reference to Fig.4, the input flow must be evaluated with eqs. (10), (11) or (11bis), in the situation of waste disposal in use, just before capping, that is in the situation of maximum height of waste overloading the drainage system.
Then the required flow-rate Q_{req} must be evaluated by eq.(23), where the Factor of Safety FS_1 to be used depends on the applied pressure and the type of draining geosynthetic, according to Tab.1.

For the selection of the geonet, the input values for the (Q,σ,i) diagrams and, when needed, for eq.(24) will be as follows.

- On side slopes, in point B:

$$i = i_s = H / L_s = \mathrm{sen}\,\alpha \qquad (25)$$

$$\sigma = \sigma_b = \gamma_r \cdot H_{rb} \cdot \tan^2\left(45° - \frac{\phi_r}{2}\right) \qquad (26)$$

$$\phi_r = 20° \div 27° \qquad (27)$$

with: γ_r = unit weight of compacted wastes [kN/m3];
H_{rb}= maximum height of waste in point B (see Fig.4) before capping [m];
ϕ_r= internal friction angle of waste materials [deg].

Designing according to eq.(25) guarantees that the liquid flow will always be at atmospheric pressure, also with full channels flow in the geonet.

Eq.(26) assumes a Rankine-type active pressure of the compacted wastes against the drainage system, the angle of internal friction being given by eq.(27) [Cancelli&Cossu, 1987].

- On the bottom, with reference to Fig.11, the hydraulic gradient is given by :

$$i_f = \delta_h / L = \frac{h_{\max} + L_b \cdot \mathrm{sen}\,\alpha_2}{L_b / \cos\alpha_2} \qquad (28)$$

Therefore, in point C :

$$i = i_f = \frac{h_{\max} + L_b \cdot \mathrm{sen}\,\alpha_2}{L_b / \cos\alpha_2} \qquad (29)$$

where h_{max} is given by eq. (14).

h_{max} according to eq.(14), is the maximum hydraulic head allowable on the geomembrane, according to the American regulation [E.P.A. 1985].
Using eq.(29) and (14) for the design of geonets guarantees that the hydraulic head on the geomembrane will always be modest.
The pressure applied to the drainage system is:

$$\sigma = \sigma_b = \gamma_r \cdot H_{rc} \qquad (30)$$

with: H_r = maximum height of waste in point C (see Fig.4) before capping [m].

3.2 Drainage of leaks from the primary geomembrane

With reference to Fig.12, the liquid leaking from a hole in the primary geomembrane spreads laterally until it flows on a fixed width Bf.
In this condition and allowing a certain excess flow near the hole, the required specific flow-rate is :

$$Q_{req} = FS_2 \cdot Q_{hole} / B_f \tag{31}$$

with Q_{hole} given by eq. (17).

The final flow width B_f depends on the flow-rate Q_{hole}, the inclination α and the type of geodrain: for a typical HDPE geonet, B_f can be evaluated from Fig.13.

The Factor of Safety FS_2 to be used must be obtained from Tab.1 : FS_2 values are lower than FS_1 values because the hazard of overflow in this case is lower.
For the selection of the geonet, the applied pressure must be obtained by eq.(30), while the hydraulic gradient must be evaluated in the most critical condition, that is when the hole in the geomembrane occurs in point B. In this case the hole is under the maximum hydraulic head and is placed in the farthest point from the collector well.
Therefore i must be calculated by eq.(29).

3.3 Drainage between geomembranes and foundation soil

In this situation, with reference to Fig.7, the required specific flow-rate is :

$$Q_{req} = Q_f \cdot FS_2 \tag{32}$$

with: Q_f = specific flow-rate reaching the drainage system between the soil and the bottom liner.

The Factor of Safety FS_2 is reported in Tab.1.
To select the geonet, with reference to Fig.7, the hydraulic gradient is:

$$i = i_f = \frac{p_f + h_f}{L_f} \tag{33}$$

with: p_f = piezometric head of the water flowing in the soil [m];

h_f = vertical distance between the water inlet and the entrance in the collector well [m];
L_f = total distance along the geonet between the water inlet and the collector well [m].

If p_f is unknown, for sake of safety it's better to assume:

$$i = \frac{h_f}{L_f} \qquad (34)$$

The most severe condition for the applied pressure occurs after capping, therefore the pressure to be used to select the geonet is:

$$\sigma = \sigma_f = \gamma_r \cdot H_r = \gamma_c \cdot H_c \qquad (35)$$

with: γ_r = unit weight of compacted wastes [kN/m³];
γ_c= unit weight of cover soil [kN/m³];
H_r = maximum height of waste [m];
H_c= thickness of soil cover [m].

3.4 Drainage of the capping

With reference to Fig.14, Q_e and Q_a, in points E and A, can be obtained with eq.(12) and (13).

The required specific flow-rates in points E and A can be obtained with eq.(23), where for the Factor of Safety the value FS_3 from Tab.1 must be used.

The pressure applied to the capping drainage system is low, but there is sliding hazard of the cover soil if the water goes under pressure : therefore, according to Tab.1, FS_3 must be rather high for compressible, and subject to high compression creep, drainage products.

To select the geonet the following values are to be used :

$$\sigma_e = \sigma_a = \gamma_c \cdot H_c \qquad (38)$$

$$i_e = \operatorname{sen} \alpha_3 \qquad (39)$$

$$i_a = \operatorname{sen} \alpha_4 \qquad (40)$$

with γ_c, H_c ,α_3 ,α_4 as above defined.

Using eq. (39), (40) for the hydraulic gradient, in points E and A, guarantees that the liquid flow is always at atmospheric pressure.

4. CONSTRUCTION DETAILS

After having completed all the calculations, it's necessary to prepare the design drawings with all the details needed to realise the waste disposal in the correct way.
The most part of the design details are of common practice, therefore only some simple design details related to the specific use of geosynthetics need to be shown here.
In particular, Fig. 15 shows the correct layout to overlap the geonets and the geotextiles at the edges along the slopes.
To avoid downward movements of the different layers along the side slopes, all the geosynthetics must be anchored in the top trench, as shown in Fig. 16.
The main trench on the bottom of the landfill is very important since it collects all the liquids toward the collector well, where they are pumped at the ground level and then treated or recirculated: Fig. 17 and Fig. 18 shows how the main trench and the collector well can be realised.
Finally, Fig. 19 shows the gas venting system, which allows a free flow toward the atmosphere to gases coming from the soil beneath the bottom liners.

5. REFERENCES

Andretta, F., Comolli, P., Guglielmetti, M. (1988), "Aggiornamenti sulle problematiche di trattamento e smaltimento del percolato di scarico controllato dei rifiuti urbani", Acqua- Aria, n. 3-88, pp. 355-361.

Bonaparte, R., Beech, J.F., Giroud, J.P. (1987) - "Background document on bottom liner performance in double-lined landfills and surface impoundments", U.S. E.P.A., Report EPA/530-SW-87-013, Washington, DC, USA.

Cancelli, A. & Cazzuffi, D. (1987), "Permittivity of Geotextiles in Presence of Water and Pollutant Fluids", Proc., Geosynthetics '87 Conference, New Orleans, USA.

Cancelli, A., Cazzuffi, D., Rimoldi, P. (1987), "Geocomposite drainage systems: mechanical properties and discharge capacity evaluation", Proc. Geosynthetic '87 Conference, New Orleans, USA.

Faure, Y.H. (1984), "Design of drain beneath geomembranes: discharge estimation and flow patterns in the case of leak", Proc. Int. Conf. on Geomembranes, Vol. 2, Denver, CO, USA.

Giroud, J.P. (1984), "Geotextiles and Geomembranes - Definitions, Properties and Design", ed. IFAI, St. Paul, Minnesota, USA, 404 pp.

Giroud, J.P. & Fluet, J.E. Jr (1986), "Quality assurance of geosynthetic lining systems", Journal of Geotextiles and Geomembranes, Vol. 3, No. 4, pp 249-287.

Hoekstra, S.E. & Berkhout, H.C. (1986), "Geotextile/"Geospacer" Composites for Environmental Projects", Proc., 3rd Int. Conf. on Geotextiles, Vienna, Austria.

Kastman, K.H., (1984), "Hazardous waste landfill geomembrane: design, installation, and monitoring", Proc. Int. Conf. on Geomembranes, Denver, CO, USA.

Koerner, R.M. (1986), "Designing with Geosynthetics", ed. Prentice-Hall, Englewood Cliffs, NJ, USA, 424 pp.

Morgenstern, R.N. (1985), "Geotechnical Aspects of Environmental Control", Proc., 11th Int. Conf. Soil Mech. Found Eng., San Francisco, USA.

Rimoldi, P. (1989), "Transmissivity and flow-rate of geosynthetic drainage products", Tenax Technical Report, Tenax SpA, Vigano', Italy.

US EPA (1985), "Minimum technology guidance on double liner systems for landfills and surface impoundments - design, construction and operation", EPA 530-SW-85-012, Cincinnati, OH, USA, 71 pp.

Van Zanten, R.V. (1986), "Geotextiles and geomembranes in civil engineering", ed. A.A.Balkema, Rotterdam, 1986.

Wiemer, K. (1987), "Le possibilita' tecniche ed operative per ridurre la quantita' di percolato", Proc. Int. Landfill Simp., Cagliari, Italy.

TAB. 1 - Factors of Safety for the design of the geosynthetic drainage system

APPLIED PRESSURE	TYPE OF GEOSYNTHETIC	FS 1	FS 2	FS 3	NOTES
$\sigma \leq$400 kPa	HDPE geonet	3÷5	2÷3	3÷5	FS takes into account the elastic compression and the occlusion of the geonet by the geotextile
σ > 400 kPa	HDPE geonet	5÷10	3÷6	-	FS takes into account also the compression creep of the geonet
$\sigma \leq$ 400 kPa	LDPE or foamed geonet; nylon or PP mat	5÷10	3÷6	5÷8	FS takes into account also the compression creep of these geodrains occurring at low pressure
σ > 400 kPa	LDPE or foamed geonet; nylon or PP mat	10÷15	6÷10	-	FS accounts also for the high compliance of the structure of those geodrains

FS1: Primary drainage system for collecting leachate

FS2: Drainage of leaks from the primary geomembrane

AND

Drainage between geomembranes and foundation soil

FS3: Drainage of the capping