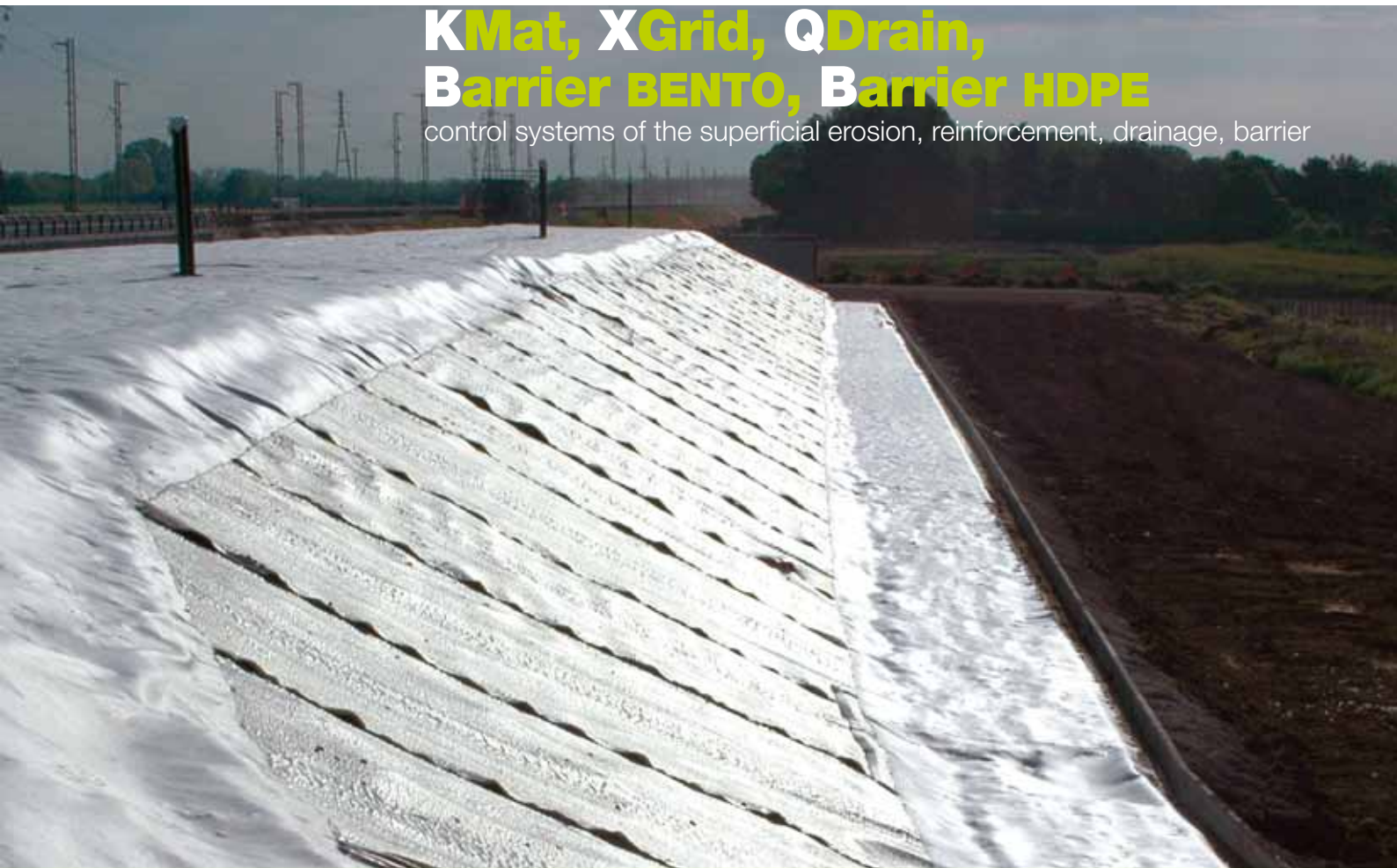


TeMa
Technologies
and Materials

KMat, XGrid, QDrain, Barrier BENTO, Barrier HDPE

control systems of the superficial erosion, reinforcement, drainage, barrier



LANDFILLS AND CONTAMINATED SITES

control systems of the superficial erosion,
reinforcement, drainage, barrier



Safety in the designing of controlled landfills

The controlled landfills today represent an area of significant social and economical interest.

All types of waste must be kept insulated in time to protect the environment and people's health.

However, this work has designing, realisation and management costs of strong impact on the balance sheets of the individual bodies and, indirectly, of the citizen.

Tema, company specialised in the drainage, reinforcement, superficial erosion control, barrier systems places its ten year experience at the service of designing. Designing with our draining geocomposites, our reinforcement geogrids, our anti-erosion geomats and our geomembranes with barrier function is easy and of proven economical saving, both for the highly efficient performances and for the high laying speed.



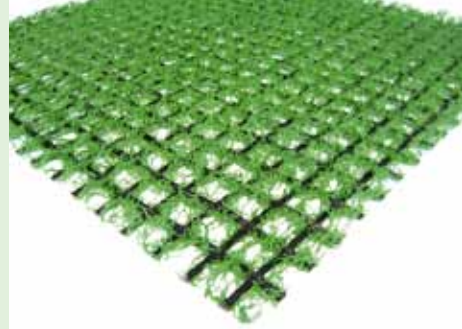
Waste storage site during realisation phase according to the TeMa method: barrier **B**, meteoric waters drainage **D**, reinforcement **R**



C CONTROL OF THE SUPERFICIAL EROSION



K-Mat L



K-Mat RF Green

R REINFORCEMENT

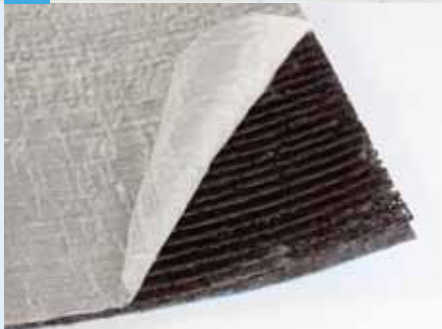


X-Grid



T-System

D DRAINAGE



Q-Drain ZW8



Q-Drain C20

B BARRIER



Barrier HDPE



Barrier BENTO



The Italian Standard regarding landfills

The realisation of this work has been, for many years now, recalling the attention of researches world-wide. The subject is certainly well known, but there are still some discrepancies in the regulations within the international panorama. The controlled disposal of waste has been regulated in Italy starting from the '80s, with a National Standard, P.D. 10/09/1982, N. 915 abrogated in 1997 with

Legislative Decree 05/02/1997 N. 22. Then, in 2003 Legislative Decree 13/01/2003 n. 36 was issued acknowledging the indications contained in European Directive 1999/31/EC, relating to waste landfills.

This important Legislative Decree encloses all aspects of the waste disposal cycle that we summarise below:

D. lgs. 13/01/2003 n°36

- Art. 1 Aim**
- Art. 2 Definitions**
- Art. 3 Application field**
- Art. 4 Classification of the landfills**
- Art. 5 Reduction aims of the appointment of waste landfills**
- Art. 6 Waste not admitted in the landfill**
- Art. 7 Waste admitted in the landfill**
- Art. 8 Authorisation request**
- Art. 9 Conditions for the issuing of the authorisation of the landfills**
- Art. 10 Content of the authorisation**
- Art. 11 Admission procedure**
- Art. 12 Closing procedure**
- Art. 13 Operational and post-operational management**
- Art. 14 Financial warranties**
- Art. 15 Disposal costs**
- Art. 16 Sanctions**
- Art. 17 Provisional and final regulations**

Attached to the Decree are:

Allegato 1 Construction and management criteria of the landfill systems

Allegato 2 Operational management plan for environmental restoration, for post-operational management, for financial control and supervision.

Art. 4 of European Directive 1999/31/EC is a classification of the types of landfills:

- **landfill for inert waste**
- **landfill for non-hazardous waste**
- **landfill for hazardous waste**

Attachment 1 describes the stratigraphies for each type of landfill in detail.

In the following pages we will analyse these stratigraphies that we will compare with the American ones of the EPA (U.S. Environmental Protection Agency) and those proposed by Tema.



Materials compatibility with the Standards of reference

During designing of a landfill, particular attention is given to checking the compatibility of the chosen materials with the specific Standard of reference.

Below is the regulatory framework that regulates the use of certain materials with a special function in the application in landfill.

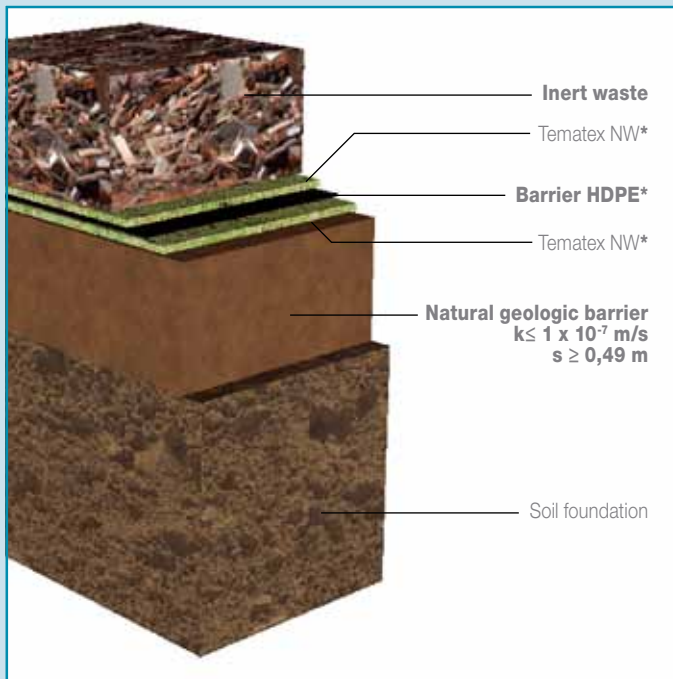
ELEMENT	FUNCTION	APPLICATION	STANDARD OF REFERENCE
Draining geocomposites	Drainage	Waste landfill liquids and solids	EN 13492
Reinforcement geogrids	Reinforcement	Liquid waste landfill	EN 13265
Reinforcement geogrids	Reinforcement	Solid waste landfill	EN 13257
Anti-erosion geomats	Control of the superficial erosion	Waste landfill liquids and solids	-
Bentonite geomembranes and geomembranes in HDPE	Barrier	Liquid waste landfill	EN 13492
Bentonite geomembranes and geomembranes in HDPE	Barrier	Solid waste landfill	EN 13493



Landfill systems for inert waste

BOTTOM AND BANKS **D B**

Stratigraphy according to Legislative Decree 36/2003



Extract from Legislative Decree 36/2003:

[...] The substrate of the base and of the sides of the landfill consists in a natural geologic formation that answers to the permeability and thickness requisites, at least equivalent to that resulting from the following criteria:

- hydraulic conductivity $k \leq 1 \times 10^{-7} \text{ m/s}$;
- thickness $s \geq 1 \text{ m}$.

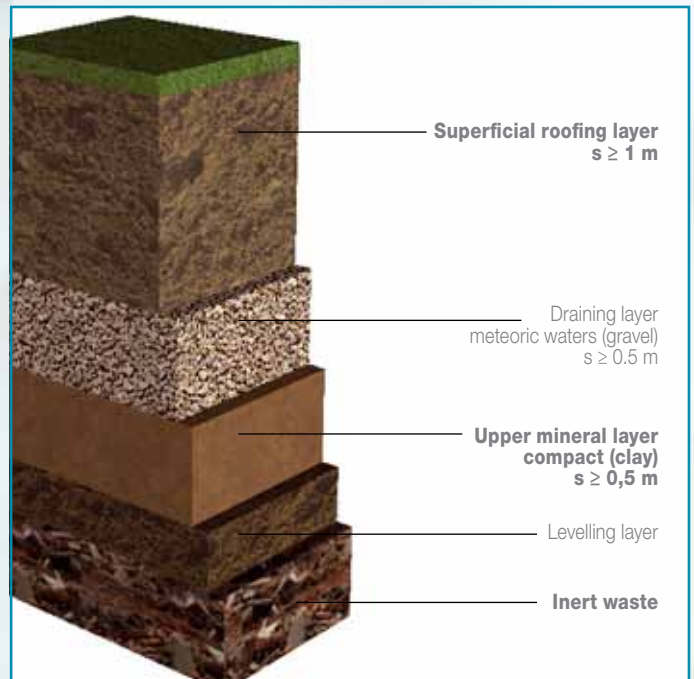
* The geological barrier, should it not naturally satisfy the above conditions (for lacking of thickness and/or hydraulic conductivity), it can be artificially completed using a confining barrier system, suitably realised to supply an equivalent protection.

The artificially set-up barrier must have a thickness not lower than 0.5 meters. [...]

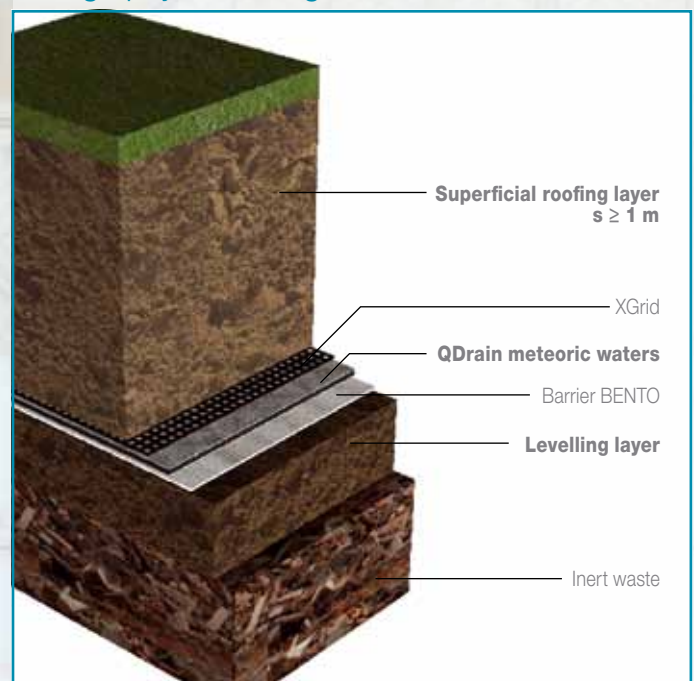
The synthetic solution that can be chosen for the creation of the artificial barrier, consists in HDPE synthetic geomembranes, Barrier HDPE type, coupled to a double protection layer in non-woven fabric, Tematex NW type.

CAPPING **C R D B**

Stratigraphy according to Legislative Decree 36/2003



Stratigraphy according to the TeMa method





Decision of the Commission dated 30 April 2009, integrating the definition of inert waste with regard to the application of article 22, paragraph 1, letter f, Directive 2006/21/EC of the European Parliament and of the Council relating to the handling of waste of the mining industries.

Article 1

1. The waste is considered inert according to article 3, paragraph 3, of Directive 2006/21/EC, when it satisfies, in the short and long term, all the following criteria:

- a) the waste does not suffer any significant disintegration or dissolution or other significant changes that might entail eventual negative effects for the environment or damages to the human health;
- b) the waste contains a maximum grade of sulphur under the form of sulphide equal to 0.1% or a maximum grade of sulphur under the form of sulphide equal to 1% if the potential neutralisation ratio, defined as ratio between the potential neutralisation and the potential acid determined on the base of a static proof compliant with Standard prEN 15875, is greater by 3;
- c) the waste does not show any self-combustion risks and is not flammable;
- d) the grade in the waste, and mainly in the fine particulate matter isolated from waste, of potentially toxic substances for the environment and for the health, in particular As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn, is sufficiently low not to entail, in the short and long term, significant risks for persons or for the environment. To be considered sufficiently low not to entail significant risks for persons and for the environment, the grade of said substances must not exceed the national limit values established for the sites classified as uncontaminated or the national background levels;
- e) the waste is substantially without products used in the extraction or in the working process that might harm the environment or the human health.

2. The waste can be considered inert without having to carry out specific trials if it can be proven to the competent authority that the criteria of paragraph 1 has been adequately taken into consideration and satisfied on the basis of the existing information or of valid plans and procedures.

3. The Member state can prepare lists of waste to be considered inert according to the criteria in paragraphs 1 and 2.

Article 2

The evaluation of the inert nature of the waste according to this decision is carried out within the framework of the waste characterisation of which in decision 2009/360/EC and is based on the same information sources.

Article 3

The Member states are addressees of this decision.

Made in Bruxelles, on 30th April 2009.



Landfill capping (levelling layer) according to the Tema method



Landfill capping according to the Tema method: geomembrane with HDPE barrier function **B**



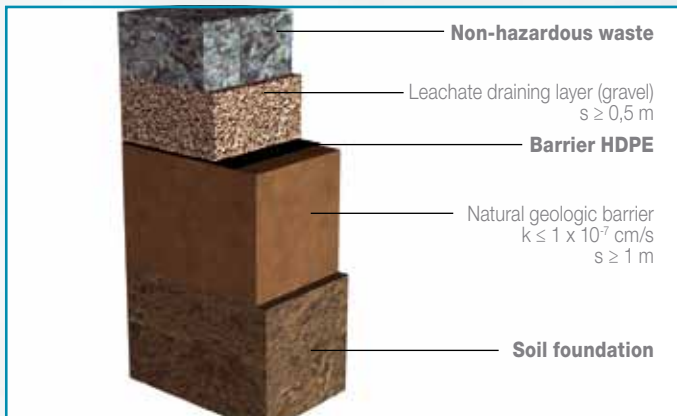
Landfill capping according to the Tema method: meteoric waters drainage with QDrain **D**



Landfill systems for non-hazardous an

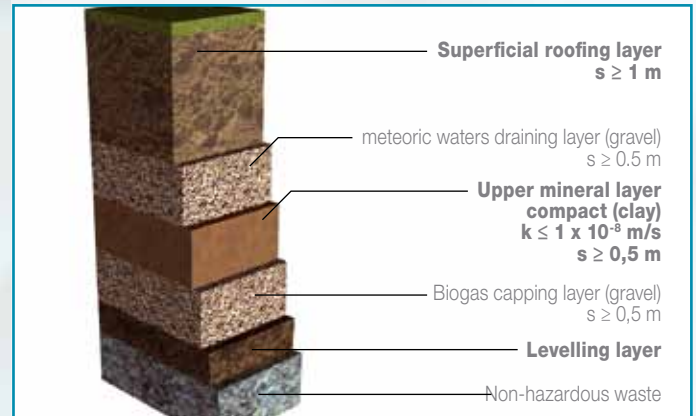
BOTTOM AND BANKS **D B**

Stratigraphy according to Legislative Decree 36/2003

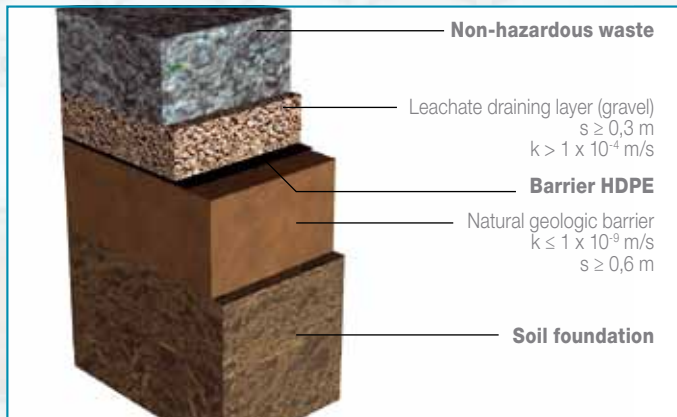


CAPPING **C R D B**

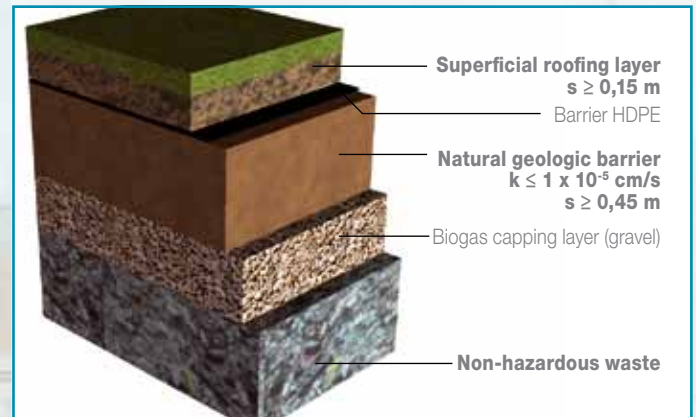
Stratigraphy according to Legislative Decree 36/2003



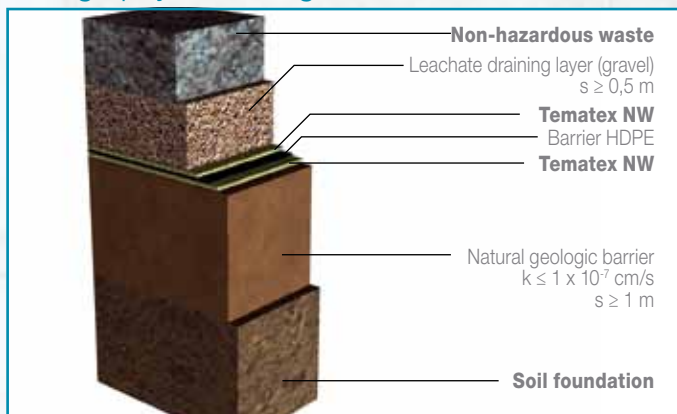
Stratigraphy according to the American D.A., US EPA



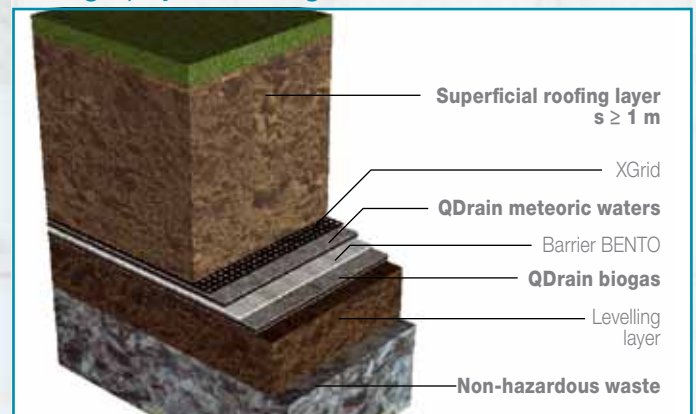
Stratigraphy according to the American D.A., US EPA



Stratigraphy according to the TeMa method



Stratigraphy according to the TeMa method





and hazardous waste

Advantages of the geosynthetics compared to natural materials

C Control of the superficial erosion

The antierosive geomats of the **K-Mat** family, protect vegetation during growing.

A strong and luxuriant vegetation protects the fill from the erosion due to wind and rain water that would expose the materials underneath to the severe meteoric action with consequent dangers of subsidence.

The presence of antierosion geomats of the **K-Mat** family, as well as protect the banks from the erosion, improves its aesthetical aspect.

R Reinforcement

The Standard does not take into consideration the different possible geometries of the landfill making the imposed prescriptions inapplicable.

In fact, if the project corner is greater than the effective friction corners between the materials, we must expect a sure sliding of the layers. This would entail damages to the barrier and draining layers. The possible solutions are:

- design less sloping landfills;
- build slopes with more berm;
- interpose **X-Grid** to the critical interface (the photo at the side presumes as critical interface that between vegetable soil and meteoric waters drain).

D Drainage of meteoric waters and capping of the biogas Drainage of the leachate and upper barrier leaks detection layer (bottom and banks)

In addition to the stability problems of the gravel over a certain slope, the large amount of gravel required must be considered (0.5 m for meteoric waters + 0.5 m for the biogas capping). In this case, the use of the draining geocomposites presents the following advantages:

- saving of about 1 m³ of waste per m² of surface;
- lower costs compared to gravel in €/m²;
- reduction of the number of movable trucks in the ratio 1:200 (with decrease of the relative transport costs and increase in the speed with which the materials reach the site);
- acceleration of the work execution times thanks to the quick laying of the GCD compared to the slowness with which gravel is laid.

B Barrier

The shape of the landfill is sometimes constituted by banks/walls with high inclinations. In these cases, the use of a GCL is able to assure waterproofing assimilable to that of 0.5 m of clay. In fact, the same rule allows (according to the principle of hydraulic equivalence) that where the natural barrier does not satisfy the requested conditions, it can be artificially completed.

There are also the following advantages:

- 0.5 m³ of waste every m² of surface are saved;
- lower costs compared to clay in €/m²;
- the number of movable trucks is reduced;
- the work execution times are accelerated.



Realisation of capping of a landfill according to Legislative Decree 36/2003: biogas drainage **D**, barrier **B**, meteoric waters drainage **D**, superficial erosion control **C**



Realisation of a landfill capping according to the Tema method: meteoric waters drainage with QDrain **D**, reinforcement with X-Grid **R**



Realisation of bottom and banks of a landfill according to Legislative Decree 36/2003: barrier with geomembrane in HDPE **B**, drainage with gravel **D**



Realisation of a landfill capping according to the Tema method: biogas drainage with QDrain **D**, barrier with bentonite geocomposite **B**, meteoric waters drainage with QDrain **D**



Stability verifications of the landfills roofing system by means of geosynthetics

The theme relating to the stability of a composite system constituted by synthetic elements (geosynthetics) and natural material (fill), surely represents one of the more significant problems for those having to design a landfill synthetic roofing system (capping or tank bottom).

The designing logic shown below is clearly also valid for the closing interventions of illegal landfills or contaminated sites in general, for which the confining technique has been chosen. Before dealing with the specifics of the algorithms that it has been decided to propose, it is incumbent to briefly introduce which have been, in time, the fundamental steps in the processing of the calculation models, that have allowed the formulating of the current theories. The first to develop specific studies on the subject were Giroud and Ah-Line.

- **Giroud and Ah-Line (1984).**

The two scientists proposed the first conceptual model that took into consideration the stabilising strengths present at the foot of the slope, the resistance mobilised in correspondence of the critical surface by the geosynthetics placed above the same, and the resistance offered by the summit anchoring trench.

- **Koerner and Martin (1985)**

Koerner and Martin proposed an analytical model, considering an infinite slope, for the case of even thickness of the soil above the geosynthetic layers, whereas a double wedge model in case of imperfect coating evenness. They only arrived at formulating the case of indefinite slope.

- **Giroud and Bech (1989)**


Subsequently, Giroud and Bech published a detailed study, analysing the three possible mechanisms that might be interested during the course of the stability verification of a composite geosynthetic system.

They considered the phenomenon correlate to the strengths generated by the interface corner along the critical surface, they analysed the entity of the strength made available by the fill located at the foot of the slope and they considered the stabilising component supplied to the system by the geosynthetics located in the upper part of the critical surface.

Finally, there are two dimensional approaches more commonly used, that envision the recourse to a conceptual model valid for a definite slope, split into two wedges (active

and passive wedge), separately developed by Giroud and by Koerner and Soong.



Capping of a landfill according to the Tema method: biogas drainage with QDrain 

- **Giroud and others (1995), Koerner and Soong (1998).**

The geometry used by the two calculation models envisions the recourse to the geometric subdivision of the definite slope portion, which object of the closing intervention, in two wedges (of active type W_1 = wedge 1 and of passive type W_2 = wedge 2).

The Giroud model and others (1995) does not envision the introduction of safety factors in correspondence of the AB horizontal sliding surface, defining instead the safety factor as a relation between the resistant strengths and the instabilising ones, relating to the active wedge (wedge 2).

With this type of approach, the scientist defines and introduces five separate components in its forming of the FS.

In this way it is easy to set a sensitivity analysis that will allow the designer to identify and quantify, in numbers, the contribution of each parameter to the system performances. Whereas, the model proposed by Koerner and Soong (1998), envisions the quantification of the stabilising and instabilising strengths, from the ratio of which, the FS value is determined.

The decisive equation of the Koerner model is a second degree equation, in the unknown FS.



Giroud and others model (1995)

Before analytically presenting the mathematical model developed by Giroud and others (1995), it is necessary to consider the hypothesis at the bottom of the method and certain definitions.

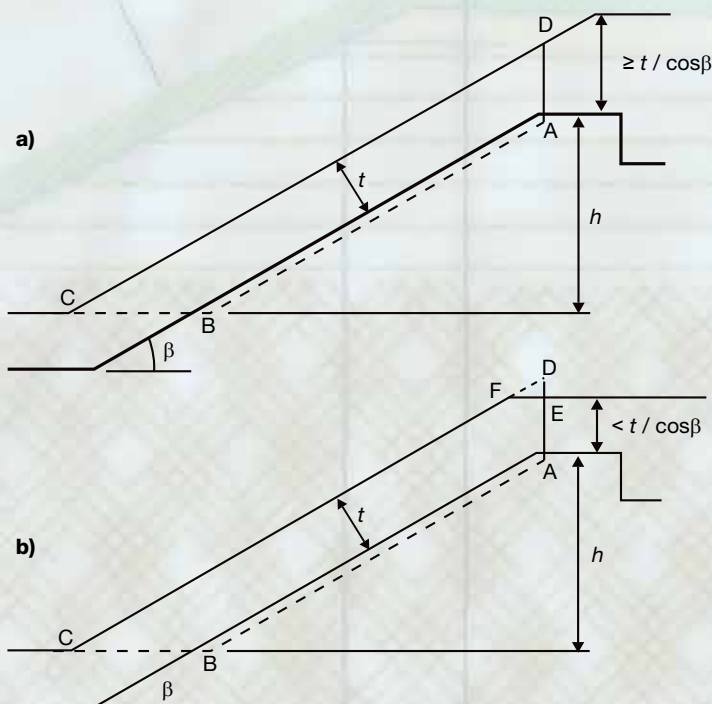
The hypothesis on which the method is based are:

- The interference of filtering strengths is not envisioned along the defined slope used to set the stability check. This does not mean that the model is not able to also manage this eventuality; however, it is necessary to introduce other parameters that are not, in this phase, indicated.
- The slope cannot be interested by a water head concerning the development of the same slope;
- The presumed geosynthetic system uses an even thickness along the whole linear development of the slope.

The main components of which the model is made are represented by:

- The critical surface is the line in correspondence of which the potential sliding of the composite system (geosynthetic-soil) can happen;
- The fill located above the critical surface of potential sliding;
- The geosynthetic(s) located above the critical surface of potential sliding.

fig. 1



The critical surface presumed by the model is shown in fig. 1, through line ABC. It has been ascertained that the horizontal line BC does not influence on how much a succession of geosynthetic products determine, upon varying of the friction corner values to the interface, the positioning of the critical surface.

It is important to note that the height of the slope (h) is measured as vertical distance between points A and B (totally similar to the Korer model).

Whereas, the parameters to be carefully evaluated, relating to the fill are:

- the " t " thickness;
- The specific weight " γ ";
- The internal friction corner " ϕ ";
- Cohesion " c ".

Finally, with regard to the geosynthetic materials part of the stratification located above the critical sliding surface, it is incumbent to observe that, in case of more elements being present, the resistance of traction T considered in the model, is given by the sum of the resistances developed by each element, in correspondence of a fixed deforming level introduced and decided during the preliminary phase by the designer. Clearly, in case the critical surface should be in the upper part of the last geosynthetic element, no value will be inserted in the analytical model, relating to the traction T resistance.



With regard to the geosynthetics elements present in the layers above the critical surface, it is incumbent to say that, for calculation of resistance **T**, only the synthetic elements able to easily support the stresses induced by external loads should be considered, therefore leaving out those elements not specifically studied to resist to prolonged traction stresses.

The method used by Giroud is based on the theory of limit balance, assuming a slope geometrically defined, subdivided in two wedges (wedge 1 and 2). The separating surface between the two wedges is taken vertically (BB'), as shown in figure 2 -a.

The strength transmitted between the two wedges in correspondence of the confining surface (BB') is to be considered parallel to the slope plan.

The starting geometrical data to be considered valid for defining the slope are the thickness "t" of the fill, the height "h" and the inclination "°".

Consider the strengths characterising wedge 1 and set the balance relations according to the limit balance theory.

Firstly define the weight of wedge 1:

$$W_1 = \frac{\gamma * t^2}{2 * \sin(\beta) * \cos(\beta)}$$

Where:

γ = specific weight of the soil located above the critical sliding surface [kN/m³];

t = fill thickness located above the critical surface [m];

β = inclination of the slope [°].

$$S_1 = \frac{c * t}{\sin(\beta)}$$

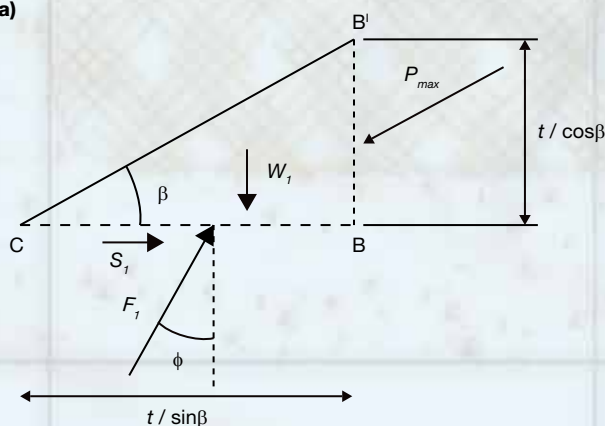
Component F1 is not known, but the value of angle ϕ is. Therefore, proceed by projecting the strengths present in wedge 1 in perpendicular direction to F1, eliminating component F1 from the analysis.

$$P_{\max} * \cos(\beta + \phi) = S_1 * \cos(\phi) + W_1 * \sin(\phi)$$

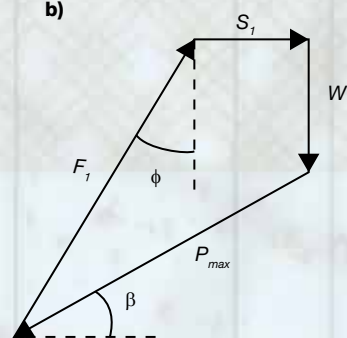
From here, knowing S_1 and W_1 , the value of P_{\max} is obtained.

fig. 2

a)



b)



$$P_{\max} * \cos(\beta + \phi) = \frac{c * t}{\sin(\beta)} * \cos(\phi) + \frac{\gamma * t^2}{2 * \sin(\beta) * \cos(\beta)} * \sin(\phi)$$



Capping of a landfill according to the Tema method: barrier with geomembrane in HDPE **B**, meteoric waters drainage with QDrain **D**, reinforcement with XGrid **R**



Whereas, with regard to the strengths of wedge 2, we will have:

$$W_2 = \frac{\gamma * h * t}{\sin(\beta)} \quad S_2 = \frac{a * h}{\sin(\beta)}$$

Where S_2 is the strength originated along plan AB for effect of the cohesive factor, generated at the interface between the soil and the critical surface.

In this case also, to get around the lacking of information regarding F_2 , the strengths will be projected in perpendicular direction to the slope.

$$F_2 * \cos(\delta) = W_2 * \cos(\beta)$$

Where:

δ = friction corner to the interface between the soil located above the critical surface and the same critical surface [°].

Now the elements for calculating the safety factor value to the sliding are known, therefore proceed by setting the relation between the stabilising components and those instabilising the system.

$$FS = \frac{F_{R/slope}}{F_{D/slope}}$$

Where:

$F_{R/slope}$ represent the stabilising components whereas $F_{D/slope}$ those instabilising.

$$F_{R/slope} = P_{max} + S_2 + T + F_2 * \sin(\delta)$$

With

$$P_{max} * \cos(\beta + \phi) = \frac{c * t}{\sin(\beta)} * \cos(\phi) + \frac{\gamma * t^2}{2 * \sin(\beta) * \cos(\beta)} * \sin(\phi)$$

$$S_2 = \frac{a * h}{\sin(\beta)}$$

T = allowed resistance of the geosynthetic(s) located above the critical surface depending on the admitted deformation;

$$F_2 * \cos(\delta) = W_2 * \cos(\beta)$$

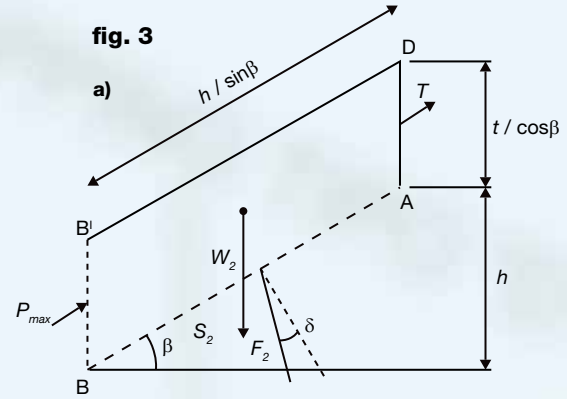
Whereas, the instabilising strengths are given by the following relation:

$$F_{D/slope} = W_2 * \sin(\beta)$$

Therefore, the arisen safety factor is the following:

$$FS = \frac{\tan(\delta)}{\tan(\beta)} + \frac{a}{\gamma * t * \sin(\beta)} + \frac{t}{h} * \frac{\sin(\phi)}{\sin(2\beta) * \cos(\beta + \phi)} + \frac{c}{\gamma * h} * \frac{1}{\sin(\beta) * \cos(\beta)} + \frac{T}{\gamma * h * t}$$

fig. 3



b)

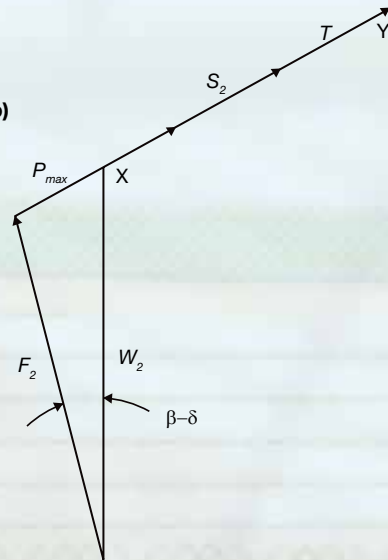
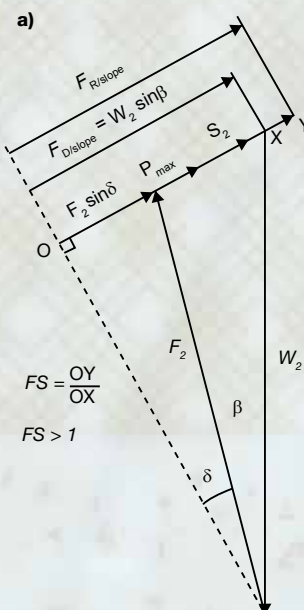


fig. 4

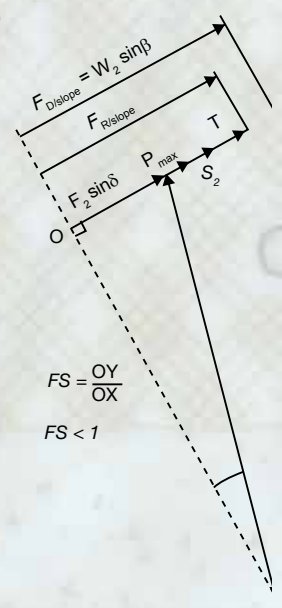
a)



$$FS = \frac{OY}{OX}$$

$$FS > 1$$

b)



$$FS = \frac{OY}{OX}$$

$$FS < 1$$



The importance of knowing the characteristic parameters of the interface gsy/gsy or gsy/soil

To study the behaviour of a geosynthetic roofing system for the definitive closing of an MSW landfill, envisions the use of calculation models that To base their reliability on the knowledge of certain mechanical parameters that depend on the materials used.

The moment a waterproofing geomembrane smooth on both sides in HDPE, a three-dimensional draining geocomposite in PP, and a layer of vegetable soil having known thickness are installed along the sloped plan (levelling layer of the waste), in correspondence of the 4 interfaces (levelling layer of the waste/GMB – GMB/GCD – GCD/GMA RF – GMA RF/final roofing soil), tensioning states are generated, in terms of friction corner to interface δ [°] and adherence a to [kPa], which values, in terms of numbers, depend on the type of surface, on the load applied on the stratigraphy and on the boundary conditions in terms of saturation degree of the soil.

The variation of these two parameters sanctions not only the overcoming of the mechanical checks on the involved liners, but also the stability check to the translation along the laying plan that the technician in charge of designing

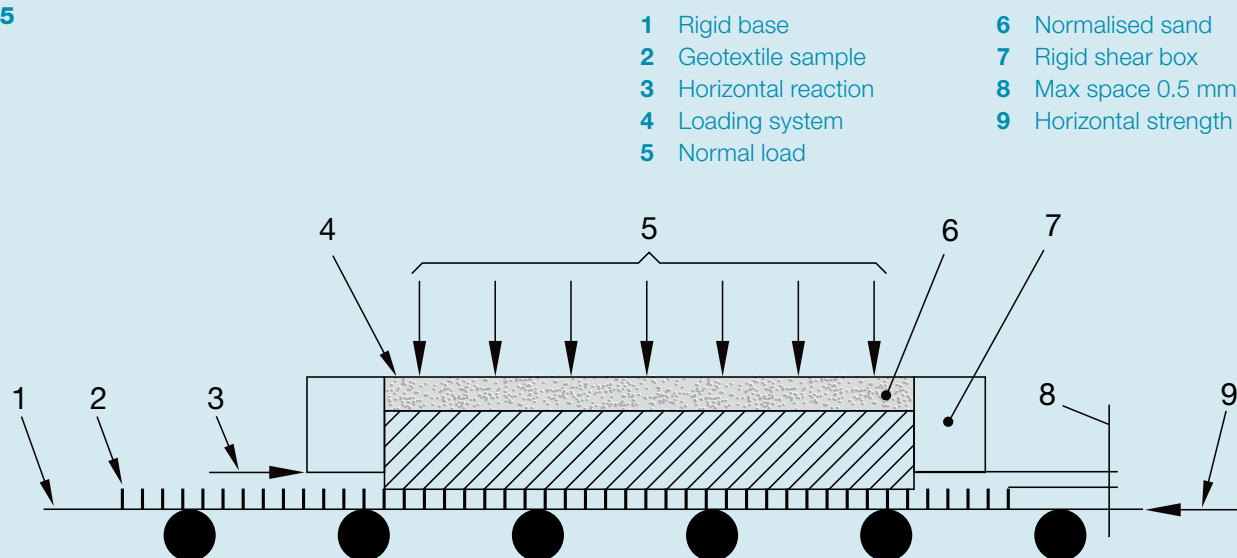
must perform to ascertain the level of safety of the roofing system.

In this regard, there are specific test procedures (the American ASTM D 5321 “Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method”, rather than the UNI EN ISO 12957-1 “Geosynthetics - Determination of friction characteristics - Part 1: Direct shear test” and UNI EN ISO 12957-2 “Geosynthetics - Determination of friction characteristics - Part 2: Inclined plane test”) that allow the calculation of the two technical parameters.

For example, the execution procedure of the direct shear test, is equipped with a rigid structure decomposed in two sections. The upper part of the shear box must have suitable internal sizes that must not be less than 300 mm (fig. 5).

Whereas, the lower structure must host the test support and that necessary to prevent that the latter slips during the test.

fig. 5





The key concept on which the logic of the test is based, is to place in direct contact the surfaces of the two materials of which the property to the interface is to be known.

Once the box has been arranged impose a normal load and a controlled movement.

At the end of the test diagrams are obtained (fig. 6) where the shear stresses [kPa] recorded to the interface are in coordinates, whereas the movement [mm] is in abscissa.

Clearly, different graphs are obtained by varying the intensity of the normal load applied.

fig. 6 - Typical diagram of a direct shear test

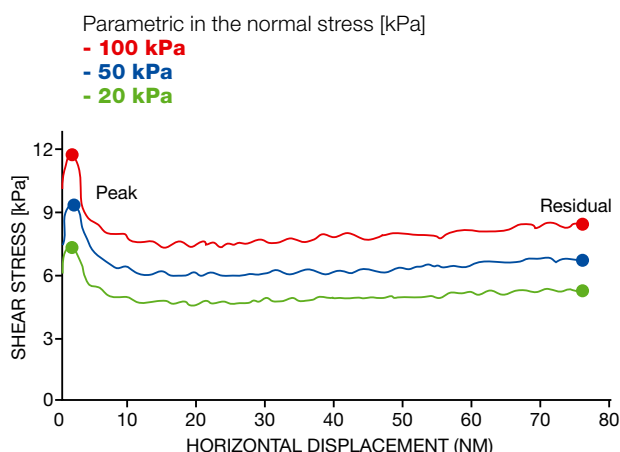
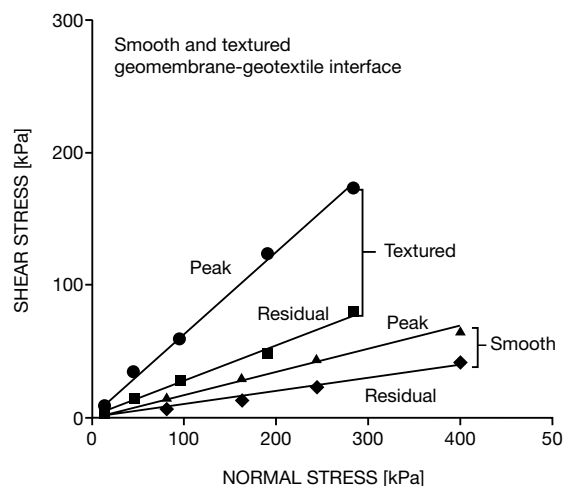


fig.7 - Critical state line



Examples of friction corners to the interface

		BARRIER BENTO	QDRAIN	TEMATEX NW	BARRIER HDPE L	BARRIER HDPE AM	SAND	GRAVEL	VEGETABLE SOIL
Bentonite geocomposite	BARRIER BENTO		18°/23°		9°/12°	28°/32°	28°/32°	30°/33°	24°/26°
Draining geocomposite	QDRAIN	18°/23°			8°/14°	28°/32°	28°/32°	30°/33°	24°/26°
Non-woven geotextile fabric	TEMATEX NW				8°/14°	28°/32°	28°/32°	30°/33°	24°/26°
Geomembrane in smooth HDPE	BARRIER HDPE L	9°/12°		10°/12°			14°/18°		
Geomembrane in HDPE with improved adherence	BARRIER HDPE AM	28°/32°		28°/32°			25°/29°		
Sand	SAND	28°/32°		28°/30°	8°/14°	22°/25°			
Gravel	GRAVEL	30°/33°		32°/34°					
Vegetable soil	VEGETABLE SOIL	24°/26°		24°/28°					



Drainage theory

Premise

The Italian Standard on landfills (**Legislative Decree 13 January 2003, n. 36 - Implementation of Directive 1999/31/EC relating to waste landfills**) envisions the use of inert material for the realisation of capping systems for liquids (meteoric waters and leachate) and aeriforms (biogas).

From the interception of the leachate (bottom) to the capping of the biogas and of the meteoric waters, the legislator has fully understood that reported by the Community Directive 1999/31/EC, underestimating technical and realisation aspects relating to the execution of these stratigraphies.

Today it is possible to propose alternative technical solutions with the use of draining geocomposites.

The methodological approach to be followed to set-up a technical comparison between the two systems is the following:

- A)** evaluate the hydraulic performances that a system made with natural inert material (ex. gravel) is able to guarantee (in terms of specific capacity q_{gravel} in l/sm or m³/sm);
- B)** evaluate the hydraulic performances that a synthetic draining geocomposite (ex. QDrain ZW8) is able to guarantee (in terms of specific capacity q_{GCD} l/s m or m³/sm), and in terms of nominal transmissivity $q_{\text{GCD}_{\text{nom}}}$ and of allowed transmissivity $q_{\text{GCD}_{\text{all}}}$;
- C)** introduce the performance factor of merit that objectively sanctions the validity of the alternate proposed solution.

Calculation of the hydraulic performances of a layer of natural inert

To evaluate the capacity that a draining layer in natural material is able to guarantee, firstly evaluate the boundary flow conditions and define if these can return to conditions of laminar flow type. Even if condition of complete saturation of the layer is also considered applicable, then it would be legitimate to consider valid the Darcy report, from which the capacity data Q [m³/s] of the searched gravel layer can be deduced:

$$Q_{\text{gravel}} = k_{\text{gravel}} * A * i = k_{\text{gravel}} * L * t * i \quad [\text{m}^3/\text{s}]$$

$$q_{\text{gravel}} = \frac{Q_{\text{gravel}}}{L} = k_{\text{gravel}} * t * i \quad [\text{m}^3/\text{sm}]$$

Where k_{gravel} is the permeability data [m/s], i is the hydraulic gradient data [ad.] and t is the thickness [m].

Example of calculation of the hydraulic performances of a layer of natural inert.

The maximum specific disposable hydraulic capacity must be calculated from a layer of $t = 50$ cm of gravel having an average value of permeability equal to $k = 10^{-3}$ m/s, placed on a plan sloped by 3° .

Assuming the Darcy report is valid, the data of the specific hydraulic capacity [l/sm] is easily obtained by applying the following analytical relation:

$$q_{\text{gravel}} = \frac{Q_{\text{gravel}}}{L} = k_{\text{gravel}} * t * i$$

placing the value of the hydraulic gradient $i = \text{sen}(\beta)$

with $\beta = 3^\circ$

$$q_{\text{gravel}} = 10^{-3} * 0,5 * 0,05 = 0,025 * 10^{-3} \text{ m}^2/\text{s} = 0,025 * 10^{-3} \text{ m}^3/\text{sm} = 0,025 \text{ l/sm}$$



Calculation of the nominal hydraulic performances of a geosynthetic draining layer (nominal transmissivity)

To calculate the specific capacity that a synthetic draining system (draining geocomposite) is able to evacuate, it is necessary to define two categories of parameters:

- Hydraulic parameters;
- Mechanical parameters.

The hydraulic parameter that it is necessary to know is the hydraulic gradient (i) that substantially expresses the inclination of the plan on which the geosynthetic system will be installed (remember the analytical relation between " i " and the plan inclination corner " β " = $\text{sen}(\beta)$)

Whereas, with regard to the mechanical parameter, it refers to the entity of the loads applied on the product (which can be permanent, variable or even cyclical).

Despite the hydraulic gradient and load applied values are known, the reading of the researched nominal hydraulic transmissivity data is immediate (specific capacity in the product plan in terms of l/sm or in m³/sm), analysing the technical sheet of the product.

Given that the technical sheets relating to the synthetic systems are conceived and realised limiting loads/gradients combinations, a maximum of 9 hydraulic transmissivity values will be available, each deriving from the combination of a load value with an hydraulic gradient data.

Therefore, it can happen that the researched data of specific capacity of the geocomposite must refer to a load/gradient combination not present on the technical sheet.

In this case, a quick formula (Rimboldi '89) can be used that will approximate the searched data.

$$q_{il} = q * \sqrt{\frac{i_l}{i}}$$

Where:

- q_{il} = searched specific capacity relating to the conditions in situ;
- q = specific capacity known from technical sheet;
- i_l = hydraulic gradient relating to the conditions in situ;
- i = hydraulic gradient inserted in technical sheet.

Example of calculation of the nominal hydraulic transmissivity.

The possibility must be evaluated of replacing a gravel draining layer dealt with in the previous calculation example with a synthetic draining system.

Therefore, calculate the value of nominal transmissivity:

with regard to hydraulic parameter (i), take the same data used for the case with gravel ($\beta = 3^\circ$ with $i = 0.05$), whereas for the mechanical parameters, consider that the synthetic draining system will be subject to a static load equal to 20 kPa (having considered a fill layer 1 m thick having a specific weight of 20 kN/m³) and a variable load due to working means eventually circulating on the installed layer equal to 50 kPa.

The total load on the product is equal to 70 kPa approximate at 10 kPa to lead us to a data usually present in the technical sheets of these systems.

The transmissivity data that must be searched for inside the product technical sheet will be that relating to the applied pressure combination = 100 kPa / hydraulic gradient = 0.04, and is equal to $q = 0.41$ l/sm, presuming to consider the QDrain ZW8 14P geocomposite.

Then, by applying the Rimoldi formula (1989) we will have:

$$q_{il} = q_{nom} = 0,41 * \sqrt{\frac{0,05}{0,04}} = \approx 0,46 \text{ l/sm}$$

a nominal transmissivity value equal to 0.46 l/sm.



Calculation of the admitted hydraulic performances of a geosynthetic draining layer (allowed transmissivity)

Once the nominal hydraulic transmissivity data is obtained, proceed to calculating the relative allowed value.

In reading, there are various analytical approaches that lead to the definition of the allowed value, starting from the nominal data.

This is where it was decided to take into consideration the approach introduced by the GRI (Geosynthetic Research Institute) according to the GRI-GC8 standard protocol – *Determination of the Allowable Flow Rate of a Drainage Geocomposite*. The calculation method used by the American institute is based on the following relation:

$$q_{allow} = \frac{q_{100}}{[RF_{creep} * RF_{bc} * RF_{cc}]}$$

Where:

q_{allow} = allowed transmissivity [l/sm];

q_{100} = transmissivity calculated following hydraulic tests having a minimum duration equal to 100 hours [l/sm];

RF_{creep} = reduction factor for creep of the internal structure [ad];

RF_{bc} = reduction factor for biological phenomenon [ad];

RF_{cc} = reduction factor for chemical phenomenon [ad].

The reasoning that leads to setting the calculation of the allowed transmissivity value according to such procedure is based on the evident physical and mechanical decay of the system in time.

It is therefore fundamental to know the behaviour in time of the system to be able to evaluate its performances, not only upon laying but also during the course of its useful life-span.

In this regard, the creep tests on the internal part of the geocomposite (three-dimensional draining soul) are fundamental. We therefore report, for explanatory purposes, the relation used by the GRI to calculate the reduction factor for creep:

$$FS_{creep} = \left[\frac{\left(\frac{t_{100}}{t_{original}} \right) - (1 - n_{original})}{\left(\frac{t_{>100}}{t_{original}} \right) - (1 - n_{original})} \right]^3$$

Where:

$t_{original}$ = original thickness of the GCD [mm];

t_{100} = thickness of the GCD after the 100 hours [mm] test;

$t_{>100}$ = thickness of the GCD after the test lasting over 100 hours [mm];

$n_{original}$ = initial porosity.

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

Where:

ρ = density [kg/m³];

μ = mass per surface unit [kg/m²].

With regard to the other two categories of reduction factors (RF_{bc} - biological clogging and RF_{cc} - chemical clogging) refer to the table below for the numerical range recommended by Koerner '98.

Example of calculation of the allowed hydraulic transmissivity.

Consider assuming the following values for the GCD:

$$RF_{creep} = 1,3$$

$$RF_{bc} = 1,8$$

$$RF_{cc} = 1,2$$

By using the previous formula we have:

$$q_{GCD_{all}} = \frac{q_{nom}}{[RF_{creep} * RF_{bc} * RF_{cc}]} = \frac{0,46}{[1,3 * 1,8 * 1,2]} = 0,163 \text{ l/sm}$$



Range of clogging Reduction Factors (modified from Koerner, 1998)

Application	Chemical Clogging (RF _{cc})	Biological Clogging (RF _{bc})
Sport fields	1.0 to 1.2	1.1 to 1.3
Capillary breaks	1.0 to 1.2	1.1 to 1.3
Roof and plaza decks	1.0 to 1.2	1.1 to 1.3
Retaining walls, seeping rock and soil slopes	1.1 to 1.5	1.0 to 1.2
Drainage blankes	1.0 to 1.2	1.0 to 1.2
Landfill caps	1.0 to 1.2	1.2 to 3.5
Landfill leak detection	1.1 to 1.5	1.1 to 1.3
Landfill leachate collection	1.5 to 2.0	1.1 to 1.3

Calculation of the quality performance factor

Use the formula:

$$FS = qGCD_{all} / q_{gravel}$$

Example of calculation of the quality performance factor.

By using the above formula we have:

$$FS = \frac{0,163}{0,0262} = 6,22$$

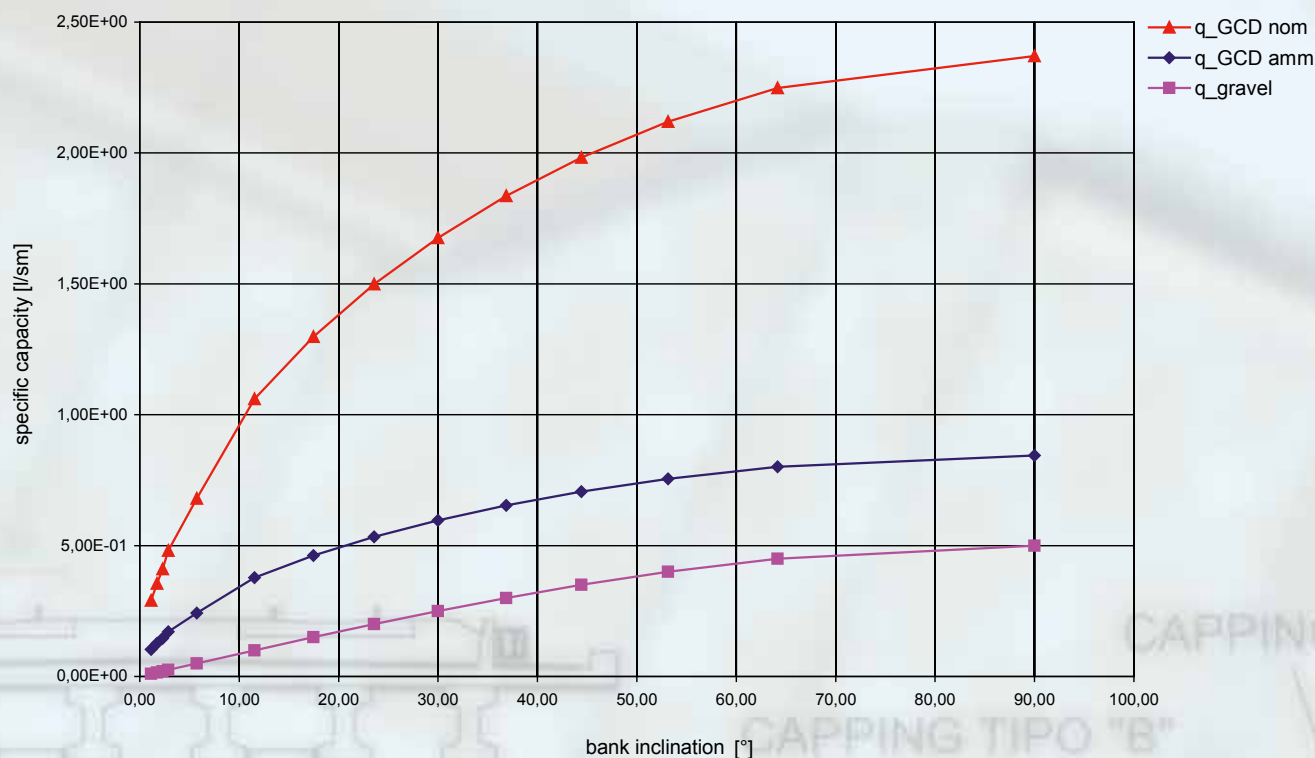
Therefore, in case the data relating to the safety factor is > 2, it is considered that the performance comparison GCD/gravel is fully in favour of the synthetic solution, justifying the recourse to such alternative.

Results shown in the following calculation sheet:

k =	1,00E-03 m/s	permeability of the gravel
t =	0,5 m	thickness of the layer
i = sen (β) =	0,05 -	hydraulic gradient
β =	3 °	slope of the laying plan
q _{gravel} =	2,62E-05 m³/sm 2,62E-02 l/sm	transmissivity of the GRAVEL layer
i = sen (β) =	0,05 -	hydraulic gradient
β =	3 °	slope of the laying plan
P ₁ =	20 kPa	permanent loads
P ₂ =	50 kPa	variable loads
P ₃ =	0 kPa	cyclical loads
P _{tot} =	70 kPa	total loads
q =	0,41 l/sm	transmissivity listed in technical sheet
	-	at 100 kPa and i= 0.04
i ₁ =	0,05 -	hydraulic gradient relating to the conditions in situ
i =	0,04	hydraulic gradient listed in technical sheet
q _{i1} = q * √(i ₁ /i) =	0,46	hydraulic gradient listed in technical sheet
q _{i1} = qGCD _{nom} =	4,58E-04 m³/sm 4,58E-01 l/sm	nominal transmissivity of the GCD
RF _{creep} =	1,2	reduction factor for creep
RF _{bc} =	2,2	reduction factor for biological aspects
RF _{cc} =	1,1	reduction factor for chemical aspects
RF _{tot} =	2,81	total reduction factor
q GCD all =	1,63E-04 m³/sm 1,63E-01 l/sm	allowed transmissivity of the GCD
FS = qGCD _{all} / q _{gravel} =	6,22	quality factor



Transmissivity value of the geocomposite and of the gravel upon increasing of the inclination of the bank



Landfill capping according to Legislative Decree 36/2003: biogas drainage with gravel **D**, clay barrier **B**, meteoric waters drainage with gravel **D**.



Landfill capping according to the Tema method: biogas drainage with QDrain **D**, barrier with bentonite geomembrane **B**, meteoric waters drainage with QDrain **D**.



Biogas capping layer

Also for the biogas capping system, obviously envisioned only for systems that also treat the degradable fractions of the waste, the Italian Standard envisions the use, during definitive closing of the system, of a 50 cm layer, minimum, of inert material (fig. 8).

Similarly to that shown for the case with interception of the meteoric waters, the solution envisioned for the handling of the biogas produced is not without problems of technical and managing nature.

From a technical point of view, there is the matter relating to the execution of the 50 cm layer along a "very inclined" plan (sometimes characterised by inclination corners above 40°). The intrinsic stability of the system, especially in time, is a sometime neglected aspect but that might generate, during the managing phase, a few problems for the body managing the site.

From a managing/logistic point of view, the diseconomy associated to such a solution is undoubted, given the volumes of inert material to be laid, with the negligible loss of useful storage volume.

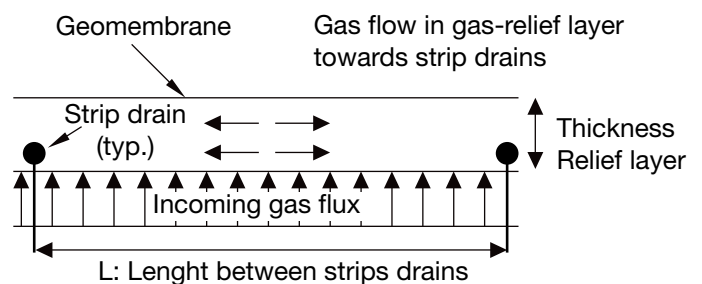
A possible alternative solution, is the installation of appropriate geosynthetic drainage systems that, thanks to their intrinsic properties, are able to represent a valid alternative not only for handling liquids (see interception layer of the meteoric waters) but also of the aeriforms (see interception layer of the biogas).

Technically, to evaluate the possibility of using a draining geocomposite as capping layer of the biogas, it is necessary to follow the steps below:

- Estimate the amount of biogas potentially generated by the waste present in the system;
- Calculate the value of nominal transmissivity requested necessary for the geocomposite to be able to handle the amount of biogas produced (nominal transmissivity requested for aeriforms);
- Calculate the data of allowed transmissivity requested for aeriforms starting from the data of nominal transmissivity requested for aeriforms, applying suitable reduction factors;
- Set the relation of equivalence that enables calculating, starting from the value of allowed transmissivity requested for aeriforms (biogas), the value of allowed transmissivity requested referred to a liquid (water);
- Calculate the value of allowed hydraulic transmissivity of the GCD chosen according to the boundary conditions of the problem (pressure applied to the GCD and hydraulic gradient) starting from the nominal data, always applying the suitable reduction factors;
- Introduction of the FS factor of merit that will compare the data calculated in point D with the data of point E.



fig. 8 - Landfill capping according to Legislative Decree 36/2003: biogas drainage with gravel **D**, clay barrier **B**, meteoric waters drainage with gravel **D**.



Estimate of the annual production rate of biogas

To carry out this evaluation, refer to the following analytical relation (source *Design of Lateral Drainage Systems for Landfills*, 2000):

$$Q_{gas} = r_{gas} H_{average\ waste} \gamma_{waste}$$

Where:

Q_{gas} = biogas specific capacity [$m^3/s/m^2$];

r_{gas} = biogas production rate [$m^3/kg/year$];

$H_{average\ waste}$ = average height of the waste stored in landfill [m];

γ_{waste} = specific weight of the waste [kN/m^3].



Calculation of the value of nominal transmissivity requested for aeriforms ($\theta_{\text{gas request}}$)

To evaluate the minimum value requested in terms of transmissivity that the synthetic system must be able to guarantee, the following relation is applied (Thiel, 1999):

$$\theta_{\text{gas request}} = \frac{Q_{\text{gas}} \gamma_{\text{gas}}}{u_{\text{gas} \cdot \text{max}}} \left[\frac{L^2}{\delta} \right]$$

Where:

Q_{gas} = biogas specific capacity [$\text{m}^3/\text{s}/\text{m}^2$];

γ_{gas} = gas specific weight [kN/m^3];

$u_{\text{gas max}}$ = maximum pressure of the gas under roofing [kPa];

L = distance between the draining collectors [m];

Calculation of the value of allowed transmissivity requested for aeriforms ($\theta_{\text{all gas}}$)

once the value of minimum transmissivity requested (nominal value) is obtained, it will be necessary to use the usual relation that will allow to obtain the allowed data (gas), through the introduction of the reduction factors:

$$\theta_{\text{all gas}} = \theta_{\text{gas request}} \prod_{i=1}^5 FS_i$$

Where:

$$\prod_{i=1}^5 FS_i = FS_{\text{IN}} * FS_{\text{CR}} * FS_{\text{CC}} * FS_{\text{BC}} * FS_{\text{OVERALL}}$$

FS_{IN} = corrective factor upon intrusion of the geotextile inside the draining core;

FS_{CR} = corrective factor due to the creep phenomenon;

FS_{CC} = reduction factor to the chemical clogging phenomenon;

FS_{BC} = reduction factor to the biological clogging phenomenon;

FS_{OVERALL} = main reduction factor.

Relation of equivalence

Through the recourse to the following relation of equivalence, it will be possible to estimate the transmissivity data in relation to liquid substances, starting from the data relating to aeriforms substances:

$$\theta_{\text{all H}_2\text{O}} = \frac{\mu_{\text{gas}}}{\mu_{\text{H}_2\text{O}}} \frac{\gamma_{\text{H}_2\text{O}}}{\gamma_{\text{gas}}} \theta_{\text{all gas}}$$

Where:

$\theta_{\text{all H}_2\text{O}}$ = allowed transmissivity requested of the water [m^2/s];

$\theta_{\text{all gas}}$ = allowed transmissivity requested of the gas [m^2/s];

μ_{gas} = dynamic viscosity of the gas [m^2/s];

$\mu_{\text{H}_2\text{O}}$ = dynamic viscosity of the water [m^2/s];

γ_{GAS} = specific weight of the gas [kN/m^3];

$\gamma_{\text{H}_2\text{O}}$ = specific weight of the water [kN/m^3].

It was defined, through the last relation of equivalence, the allowed transmissivity value (long term) that our geosynthetic system must be able to guarantee.

Calculation of the value of nominal requested transmissivity of the GCD ($\theta_{\text{nom GCD}}$)

Once the allowed transmissivity requested to our system is known ($\theta_{\text{all H}_2\text{O}}$), we will have to calculate the value of allowed transmissivity that our product is effectively able to guarantee ($\theta_{\text{nom GCD}}$), depending on the boundary conditions (applied pressure and hydraulic gradient).

The calculation of the data relating to the nominal hydraulic transmissivity ($\theta_{\text{nom GCD}}$), known the parameters of the pressure applied to the product (kPa) and hydraulic gradient, is immediate by consulting the technical sheet of the selected material. Presuming the insertion of a capping layer of synthetic biogas along a plan sloped by 2.3° (corresponding to a value of hydraulic gradient of 0.04) and envisioning a data of maximum pressure applied equal to 100 kPa , it will be sufficient for the user to cross this data on the product technical sheet and read the searched nominal hydraulic transmissivity data ($\theta_{\text{nom GCD}}$).

In case the data of hydraulic gradient corresponding to the conditions in situ should not correspond to one of the three data that are usually shown in the technical sheet, it will be necessary to apply the simplified Rimoldi formula.

Calculation of the value of allowed transmissivity requested of the GCD ($\theta_{\text{all GCD}}$)

From the data of nominal hydraulic transmissivity ($\theta_{\text{nom GCD}}$) deduced from an appropriate reading of the technical sheet, calculate the allowed value ($\theta_{\text{all GCD}}$), according to the following relation (GRI standard method):

$$\theta_{\text{all GCD}} = \frac{\theta_{\text{nom GCD}}}{[RF_{\text{creep}} * RF_{\text{bc}} * RF_{\text{cc}} * RF_{\text{in}}]}$$

Where:

$\theta_{\text{all GCD}}$ = allowed hydraulic transmissivity [l/sm];

$\theta_{\text{nom GCD}}$ = nominal hydraulic transmissivity [l/sm];

RF_{creep} = reduction factor for creep of the internal structure [ad];

RF_{bc} = reduction factor for biological phenomenons [ad];

RF_{cc} = reduction factor for chemical phenomenons [ad];

RF_{in} = reduction factor for intrusion of the geotextile inside the draining core [ad].

Calculation of the FS quality factor

To check how far the proposed synthetic solution is adequate to the system requests (remember that the term of comparison is the long term transmissivity requested by the system), we will introduce an FS quality factor, defined like the ratio between allowed hydraulic transmissivity of the GCD ($\theta_{\text{all GCD}}$) and the allowed hydraulic transmissivity requested of the system ($\theta_{\text{all H}_2\text{O}}$). The solution with draining geocomposite would be considered justified in alternative to the solution with natural granular material, if the numerical value of FS should result more than 2.

$$FS = \frac{\theta_{\text{all GCD}}}{\theta_{\text{all H}_2\text{O}}}$$



Case histories

Field of application:	The geosynthetic capping of an MSW landfill	FUNCTION	FIELD OF APPLICATION
Title:	Realisation of the capping layer of the biogas, of the meteoric water and of the erosion control in the capping of an MSW landfill	SEPARATION	WATER BASINS
		FILTERING	CHANNELS
		REINFORCEMENT	ROAD EMBANKMENTS
		EROSION CONTROL	RAILWAY EMBANKMENTS
		DRAINAGE	LANDFILLS
Location:	Milan	WATERPROOFING	SYSTEMS OF DRAINAGE
Period:	2008	PROTECTION	FOUNDATIONS/WORKS SUPPORT

Premise

The Italian Standard acknowledging Community Directive 33/1999/EC on waste landfills (Leg. D. 32/2003) for the realisation of the capping layers of the biogas and of the meteoric waters, envisions the realisation of 50 cm layers of granular inert material.

For many designers/systems managers, one of the most common problems is the feasibility of the interventions, in light of the ever more existing requirements to recover useful spaces inside the sites.

The realisation of the draining layer by means of granular material along ever more inclined slopes, has induced companies dealing in geosynthetic materials, to study and propose new systems, more efficient and longer lasting, compared to the traditional solutions.

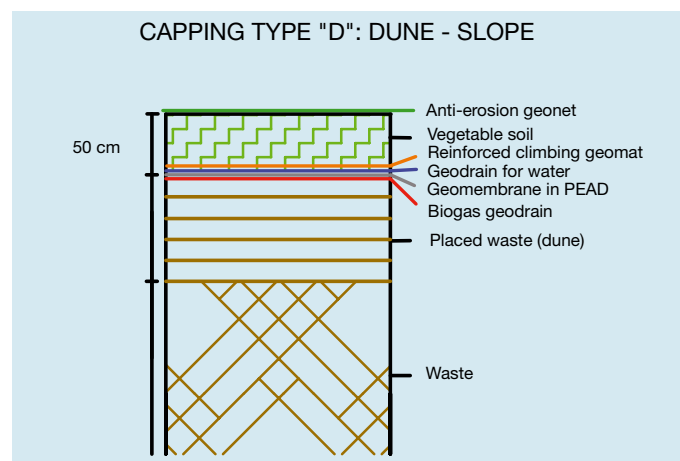
This note synthetically exposes certain technical features of materials that today represent the most efficient alternative solutions that the market is able to propose.

The synthetic solution is quicker to lay, more performing from an hydraulic point of view compared to the granular layer, with a significantly reduced thickness (8 mm compared to 50 cm of the gravel), lower impact on the costs of transporting the material to the site compared to the solution with inert (3 lorries transport material to cover 10.000 sq. m of landfill compared to conferring 5.000 cubic meters of gravel), possibility of also installing on very inclined slopes. From a technical comparison point of view, the hydraulic yield of a layer of gravel is calculated assuming as valid the Darcy relation.

Once the thickness, permeability coefficient and hydraulic gradient are defined, it is possible to obtain the value of specific draining capacity of the natural layer in terms of l/sm. In parallel, the hydraulic performance of a geosynthetic draining layer are deduced from the values reported in the technical sheet, correlating the data according to the value of hydraulic gradient and confining pressures applied on the material.

Solution used for the draining layer of the biogas

The Standard envisions the laying of a 50 cm gravel layer. In the specific case, the draining layer in correspondence of the horizontal plan has been realised with granular material, whereas for the sloping line (external slope) an 8 mm thick

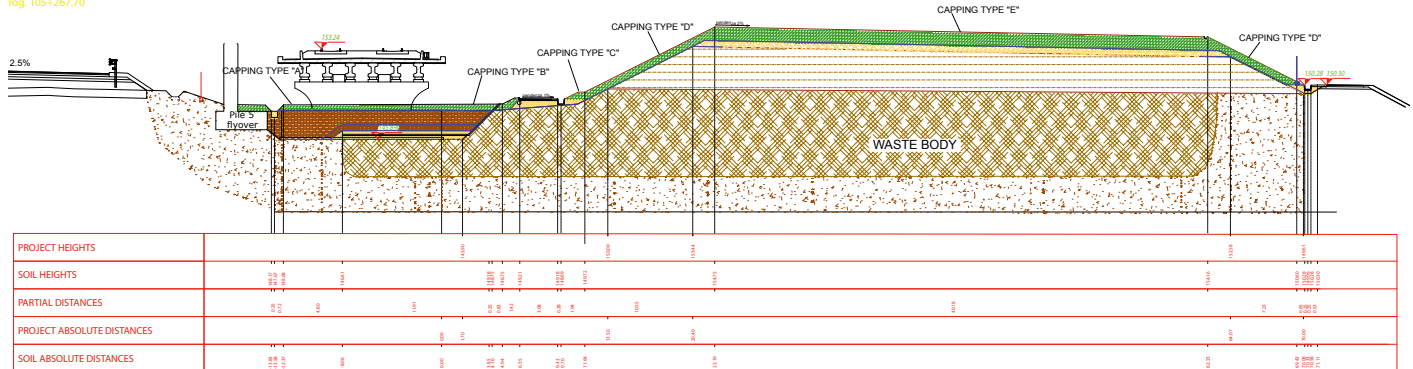




KMat, XGrid, QDrain, Barrier BENTO, Barrier HDPE

control systems of the superficial erosion, reinforcement, drainage, barrier

Centre-to-centre pile P1 - pile P2
neg. 105+267.70



draining geocomposite, QDrain ZW8 75 14P type, has been used.

The internal draining core of the product is obtained by extrusion of PP monofilaments; the given geometric structure is in parallel channels, with non-woven geotextile in PP of 140 gr/sq. m on both sides.



View of the landfill line for which the installation of the QDrain draining composite was envisioned **D** for the capping of the biogas along the slope.

an hydraulic gradient equal to 0.04, for Darcy's law, the gravel presents an hydraulic capacity equal to $2 \times 10^{-5} \text{ m}^3/\text{s m}$ equivalent to $2 \times 10^{-2} \text{ l/sm}$.



Installation phases of biogas drainage with QDrain **D**. The capping layer of the biogas has been calculated along the external slope of the system, guaranteeing greater laying speed and upper stability of the system along the sloped plan

Solution used for the draining layer of the meteoric waters

Once the capping layer of the biogas has been realised, an HDPE 2 mm thick membrane was laid to guarantee an adequate hydraulic seal of the roofing system. The subsequent layer to be envisioned was represented by the capping layer of the meteoric waters.

Instead of a 50 cm gravel layer, a second draining geocomposite QDrain ZW8 75 14P type, was positioned. The hydraulic features of the geocomposite are about 15 times above the yield of the gravel layer. Presuming a gravel with permeability 10^{-3} m/s and a thickness equal to 50 cm, with



Installation phases of meteoric waters drainage with QDrain **D**.



The draining geocomposite with confining pressure equal to 50 kPa and hydraulic gradient equal to 0.04, declares a value equal to 0.3 l/sm.

Anti-slipping layer at vegetable soil synthetic draining layer interface

A problem that might arise when installing geosynthetic systems in landfill, is the stability of the cultivated soil envisioned above the artificial layers.

To solve this problem, it is possible, through algorithms of calculation to limit balance, to dimension reinforcement layers that, placed at interface between the meteoric waters draining layer and the final roofing soil, guarantee better stability conditions to the packet.

In this specific case, a geomat was installed with high vacuum index coupled with a fabric PET geogrid having a nominal resistance equal to 80 kN/m.



The QDrain draining geocomposite **B** has been installed on top of the HDPE geomembrane **D**, for the drainage of meteoric waters. On top of the latter, it has been envisioned laying an XGrid reinforced geomat **R** to improve friction at interface with the fill.



The XGrid reinforced geomat **R** is placed above the QDrain synthetic draining layer **D** to improve the friction conditions at interface and guarantee better stability conditions upon sliding of the roofing packet. The draining geocomposite for the drainage of the meteoric waters has been installed above an HDPE geomembrane **B**.



Case histories

Field of application:	Draining of the meteoric waters in landfill	FUNCTION	FIELD OF APPLICATION
		SEPARATION	WATER BASINS
		FILTERING	CHANNELS
		REINFORCEMENT	ROAD EMBANKMENTS
		EROSION CONTROL	RAILWAY EMBANKMENTS
		DRAINAGE	LANDFILLS
		WATERPROOFING	SYSTEMS OF DRAINAGE
		PROTECTION	FOUNDATIONS/WORKS SUPPORT
Title:	Realisation of the draining layer for the collection of meteoric waters in a capping of an exhausted MSW landfill		
Location:	Veneto		
Period:	2007		

Premise

In light of this Standard on waste landfills (Leg. D. 36/2003) the drainage layer for meteoric waters is made of a 50 cm fill of natural gravel. The problem of having to realise the drainage layer also along the slopes, often very inclined, has, in recent years, suggested the use of new materials that, as well as guarantee better performance in hydraulic terms (greater hydraulic capacity values), also offer greater guarantees with regard to constant and homogenous hydraulic data for the entire area on which they are installed.

Used solution

The solution that has been used, notwithstanding Decree 36/2003, has envisioned the use of a 20 mm thick drainage geocomposite, QDrain C20P type.

The internal drainage soul of the product is obtained by extrusion of PP monofilaments; the geometrical structure that is given is double pointed, guaranteeing homogeneity and, therefore, hydraulic performance isotropy to the product. Given the loads contained to which the QDrain C20P will be subject during its useful project life, this type of material was chosen as it seemed a good compromise in terms of cost effectiveness.



Installation phase of the draining geocomposite for the draining of the meteoric waters QDrain C20 P **D**. The product will be buried underneath 1 m of vegetable soil.




Particular of the liners near the perimetrical strip of the landfill



KMat, XGrid, QDrain, Barrier BENTO, Barrier HDPE

control systems of the superficial erosion, reinforcement, drainage, barrier



Laying phase of the geocomposite for the draining of the meteoric waters QDrain C20P 



Case histories

Field of application:	Geosynthetic capping of an MSW landfill	FUNZIONE	FIELD OF APPLICATION
		SEPARATION	WATER BASINS
		FILTERING	CHANNELS
Title:	Laying of the geosynthetic reinforcement layer in the capping of an MSW landfill	REINFORCEMENT	ROAD EMBANKMENTS
		EROSION CONTROL	RAILWAY EMBANKMENTS
Location:	Ravenna	DRAINAGE	LANDFILLS
		WATERPROOFING	SYSTEMS OF DRAINAGE
Period:	2008	PROTECTION	FOUNDATIONS/WORKS SUPPORT

Premise

The Italian Standard acknowledging the II Community Directive, definitive roofing system of a municipal solid waste landfill, whether hazardous, non-hazardous or inert, is defined in Legislative Decree 36/2003, issued upon acknowledgement of Community Directive 33/1999/EC.

Te stratigraphy envisions the succession of a series of natural layers, each of which has a clearly specified function. When the final slope is very inclined, the designer has the need to insert synthetic support elements that work as reinforcement, able to reduce the stresses transmitted to the layers below, in particular if these are of geosynthetic material. In fact, in this case, it has been envisioned to place a geosynthetic draining in contact with the last roofing layer (1 m thick vegetable layer).

The geosynthetic system inserted to work as draining layer of the meteoric waters, may represent a surface of potential sliding or be excessively stressed by the system of the external loads applied to it.

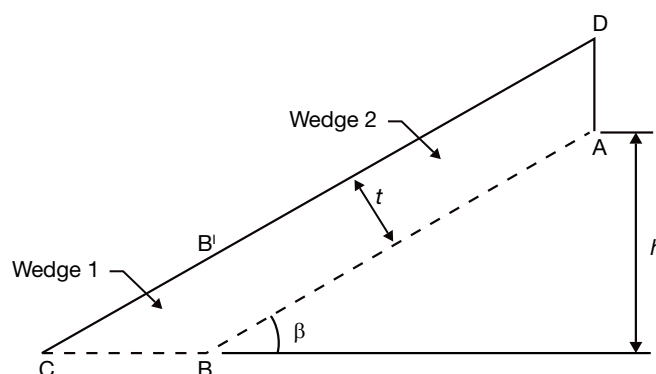
It was therefore necessary to study a solution that would make the roofing system safe from a point of view of potential transfer phenomena.

Solution used for the reinforcement layer

A reinforced geomat has been inserted at interface between the synthetic draining layer and the definitive roofing soil. To technically verify whether the synthetic reinforcement element was suitable, the problem, according to the limit balance theory, was analysed.

The algorithms of calculation used is taken from the J.P. Giroud, N.D. Williams, T. Pelte, J.F. Beech, *Stability of geosynthetic-soil layered systems on slopes*, 1995 article.

The slope, along which the laying of the synthetic reinforcement element is envisioned, is discredited by the model in two parts: active and passive wedge.



The input data requested is of different nature: relating to the covering soil, to the geometry of the slope and to the technical features of the used geosynthetic materials used.



A) data relating to the soil

$t_{terr} =$	0,30	[m]	thickness of the soil
$\gamma_{terr} =$	18,00	[kN/m ³]	specific weight of the soil
$c_{terr} =$	0,00	[kPa]	cohesion of the soil
$\phi =$	28,00	[°]	friction corner of the soil
$sen(\phi) =$	0,47		sine of the friction corner of the soil
$cos(\phi) =$	0,88		cosin of the friction corner of the soil
$c_a =$	0,00	[kPa]	adherence coefficient along plan AB
$\delta =$	20,00	[°]	friction corner at GSY/soil interface
$sen(\delta) =$	0,34		sine of the friction corner at interface
$cos(\delta) =$	0,94		cosin of the friction corner at interface

B) data relating to the geometry of the slope

$H =$	3,50	[m]	height of slope
$\beta =$	25,00	[°]	inclination of the slope
$L = H/sen(\beta) =$	8,28	[m]	length of the slope
$sen(\beta) =$	0,42		sine of the inclination corner of the slope
$cos(\beta) =$	0,91		cosin of the inclination corner of the slope
$cos(\beta+\phi) = cos(\phi) * cos(\beta) - sen(\phi) * sen(\beta) =$	0,60		

Once the input data is entered, the model is able to supply, in output, the safety factor associated to the inserted reinforcement, evaluating the safety level totally attributed to the roofing system.



Installation phases of the synthetic reinforcement layer **R** : laying happens directly above the draining geocomposite **D** + HDPE geomembrane **B**



KMat, XGrid, QDrain, Barrier BENTO, Barrier HDPE

control systems of the superficial erosion, reinforcement, drainage, barrier





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On cover: capping of an MSW landfill in Milan using geosynthetic materials

TeMa Technologies and Materials srl
via dell'Industria 21
31029 Vittorio Veneto (TV) ITALY
Tel. +39 0438 5031
fax +39 0438 503462
e-mail: info@temacorporation.com
www.temacorporation.com

Technical Department - Geosynthetic Division
corso del Popolo 56
20056 Seregno (MI) ITALY
Tel. +39 0362 245179
Fax +39 0362 242256
e-mail: tecnico@temageo.com
www.temageo.com

Tema North
142641 (FR) Moskovskaja obl.
Orehovo-zuevskij r-n
d. Davydovo
ul. Zavodskaja
Tel. /fax: +7(4964) 174204.

Tema Ibérica S.I.
C/Bélgica
Pol. Ind. de Rossanes
08769 Castellví de Rossanes
España

Tema Med Ltd.Sti.
Ege Serbest Bolgesi Mumtaz
Sok. No:23
35410 Gaziemir/Izmir Turkiye
Tel. +90 232 252 04 24
Fax +90 232 252 16 44