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CAPPING OF STEEP SLOPES, 35M LONG, AT THE CERRO MAGGIORE LANDFILL (ITALY)

Piergiorgio Recalcati and Pietro Rimoldi

TENAX SpA., Via Industria 3, 22060 Viganò Brianza (LC), Italy

SUMMARY

The landfill of Cerro Maggiore has represented in the last years one of the most important source for stocking the wastes in the area around Milano.
The landfill, due to the lack of other sites, was overfilled with wastes, piling up to form a hill, 30 m high, presenting slopes at 38° inclination, 35 m long. These slopes, according to the Italian law, had to be waterproofed with 1 m clay and covered with topsoil.
The challenge given by the inclination and the length of such slopes, forced to a careful selection of the geosynthetics, which included drainage geocomposites, GCLs, geogrids and geomats.
Even the construction details and the installation procedures had to be tailored to this specific situation.
The paper describes in details the design methods and the installation of the capping package, thus making a reference case history for these challenging projects.

1. INTRODUCTION

The capping system is one of the most challenging engineering problems in a landfill.
The designer choice for most suitable system should take into account the local environmental needs.
One of the main problems faced by environmental geotechnology is how to build landfills for urban and industrial wastes which can provide a guarantee of safe seal of the site, in order to avoid pollution to the ground and the water table.
Using modern technologies will help to obtain the best result after the closure of the waste disposal site.
In the case of drainage, the rapid advent and the very extensive use of geonets and geocomposites in landfill is due both to the advantage provided by the polymers, usually HDPE and PP, in contact with leachate (resistance to chemical aggression, durability, good resistance to the high temperatures produced by the fermentation of waste material) and to the technical characteristics of the products. Besides a good resistance to tension, geonets can resist very high compressive stresses and can carry liquids or gases along their plane, in every direction and with minimum slope. The flow rate afforded by geonets is very high even with very limited thickness. Hence geonets can substitute sand and gravel, which require much higher thickness to provide the same flow rate.
Moreover geonets can be placed almost at any slope, while the natural materials always require mild slopes to ensure stability.
Geosynthetics yield many advantages in terms of technical characteristics, but also in economical terms: comparing the cost of purchasing and installing geonets or sand, and considering the increase in available volume afforded by geosynthetics, it is easy to obtain savings of 50% when using synthetic drainage rather than the traditional one.
A capping system should be designed not only to contain the wastes and to reduce the leachate production by reducing the rain water and the surface water incoming the waste body, but also to prevent uncontrolled escape of landfill gas (biogas) and to accommodate the required environmental control measures.

2. ITALIAN LEGISLATION FOR LANDFILLS

In Italy, the construction and maintenance of a waste landfill must be designed in accordance with the D.P.R. 915/83 national act.

The legislation deals with many aspects of landfill construction, with particular attention to the possible types of wastes that can be stored, and on the documentation it is necessary to provide. As it concern the construction (side and bottom lining system and capping system), more restrictive rules, depending on the regional situation, may be enforced by the local Authorities. In particular for the capping it is required that the lining system shall be 1.00 m of clay with a maximum permeability of 10^{-6} m/s, or any other material with a permeability coefficient equivalent to 1.00 m clay. On the top of the lining system it is necessary to have an adequate protection layer and a final top soil layer.

3. DEVELOPMENT OF THE CAPPING TECHNIQUES

Conventional techniques have their drawbacks. For example, it is not always possible to place and compact natural clay. This is particularly true with steep slopes, where it is necessary to place horizontal layers, compact with a sheep-foot compactor and, finally, excavate the exceeding clay. Obviously this system is expensive and very slow. A proper system for collection and drainage of biogas from the bottom and for drainage of water from the top of the lining system should than be provided. The typical solution will consists in the use of sand and gravel, with difficulties in term of laydown and an important reduction in the landfill total available volume.

The use of geosynthetics offers a more economical and practical solution for landfill capping. A typical lining system uses (from the bottom to top): a drainage geocomposite (connected to gas collection pipes), a geomembrane or geosynthetic clay liner (GCL), a geocomposite and a final layer of top soil (thickness 200-500 mm). The two geocomposites also function to protect the geomembrane from puncture.

3.1 Geosynthetics Clay Liners

As it concerns the lining system, HDPE geomembranes are now well known in the world of landfill construction. GCL, however, have entered the market in recent years, and the products are in continuous development.

Geocomposites based on bentonite consist of a sandwich composed of two geotextiles with the interposition of a particular type of natural clay with a high montmorillonite content: sodium bentonite. The function of the two geotextiles is that of containing the bentonite in a restricted space and so facilitating their transport and, above all, their installation. Having a product of uniform thickness containing a layer of natural waterproofing material, in fact, allows the attainment of the advantages of a natural material with the easiness of installation peculiar of geosynthetics. The two geotextiles can be connected through stitches, needle punching or just gluing with an adhesive mixed with the bentonite. Typical schemes are shown in Fig. 1.

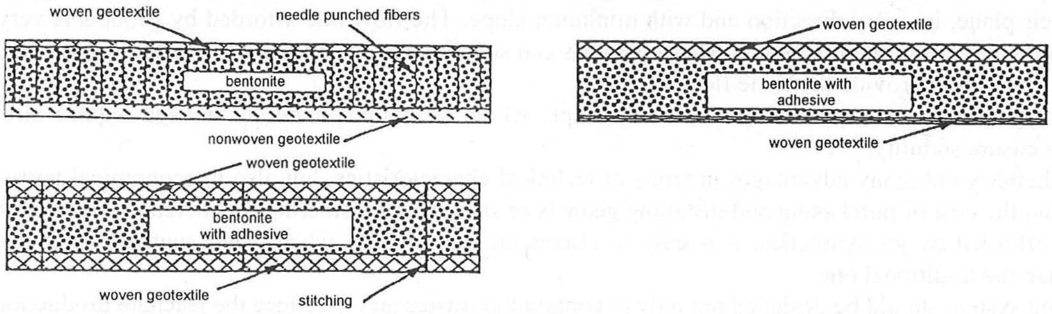

Fig. 1: typical Geosynthetics Clay Liners

The danger of perforation and difficulties with welding the sheets represent the main problems connected with the use of HDPE geomembranes. The use of GCL in landfill sites offers the following advantages. First of all, the GCL is able, by swelling, to self seal any perforation that may occur, even after the landfill has been closed down. Second, in using at least one geotextile of a woven type, part of the bentonite is able to migrate through the geotextile and, swelling, automatically seals the joints between adjacent layers. This considerably simplifies the placement operation because it provides tightness through a simple overlap of the placed sheet edges.

The self-sealing capacity of GCLs is real for small tears or holes, while large cuttings can remain partially open. Therefore it is necessary to provide a proper mechanical protection to the GCLs against puncturing and damaging by the coarse aggregate usually placed on top of the last waste layer, and from the aggregate used on slopes and berms for drainage and/or anchoring of the geosynthetics layers. Moreover, in order to be hydrated, the GCLs must be covered with at least 0.30 m of coarse soil.

At the present time, bentonite geocomposites still give rise to uncertainties which limit their distribution and use: the main concerns are their long term durability, the frictional characteristics of the interface and their internal resistance to sliding, plus the interaction with the drainage layers in contact.

Researches has been done on the behaviour of GCL, taking into considerations mechanical and hydraulic properties,

In particular, Bressi et al. (1995) have studied the interface friction between adjacent geosynthetic layers or between soil and geosynthetics; laboratory tests have been performed on several types of different materials to investigate both the internal and interface friction characteristics of two GCL products.

Montanelli and Rimoldi (1995) report on studies on the specific performances of a GCL/Drainage Geocomposite System under high compressive loads and shear loads in respect to the long term mechanical and hydraulic characteristics of the components of the system. Testing has been performed using several types of geosynthetics, including GCLs and geocomposites manufactured with a variety of geotextiles structures and geonet cores with two strands and three strands structure.

The use of GCL, however, needs particular attention due to the hydraulic permeability to gas of dry GCL; a GCL must be wetted just after laying down, and must be kept wet thereafter (Jesionek et Al., 1995). This can be done by installing a proper irrigation system on the top of the landfill, thus allowing a proper control of grass growth as well (and so, a proper control of the environmental impact of the landfill after closure).

ASTM D 35 Committee on Geosynthetics has recently approved a series of test Standards, related to GCL, which will allow engineers to properly test and specify these products.

3.2 The drainage geocomposite

With drainage geocomposites designers must give particular attention to the physical, mechanical and hydraulic properties. The materials must be chemically inert (HDPE or PP). Hydraulic properties are very important for the top geocomposite, which must be designed to discharge the maximum rainfall anticipated to fall in the area. If the drainage geocomposite is underestimated, the excess of water produces an uplifting pressure on the top soil, highly reducing the frictional behaviour and causing top soil sliding.

Cancelli and Rimoldi (1989) give details on the method to choose and design the drainage system. A properly chosen drainage geocomposite allows to consider, in the design calculation of the top soil stability, an interface friction angle greater than zero degrees; if no drainage is provided, instead, the friction angle which should be used, to take into account the undrained situation after intense rainfall, is $\phi=0°$.

Lack of proper drainage can lead to the failure of the whole capping system.

3.3 The topsoil reinforcement and protection

Sometimes the need to increase the landfill volume brings to quite steep side slopes. In these cases, the stability of the top soil can not be provided by its shear strength only. The additional resistance is usually given by a geogrid (single layer or multi-layered) or by a reinforced geomat. Finally, an erosion control geosynthetic (geomat, geocell or biomat) must be laid down on top.

Designers need to perform a stability analysis on the slope and on the trench. Stability analysis on the slope needs to take into account the friction angle at the most critical interface, the passive thrust at toe, the tension of the geosynthetic. Designers also need to evaluate the required shape, depth and length of the anchorage trench.

4. CERRO MAGGIORE LANDFILL (MILANO PROVINCE, ITALY)

As already said, the landfill of Cerro Maggiore has represented in the last years one of the most important source for stocking the wastes of the area of Milano. The extremely fast fill of the landfill (much faster than expected) has given big problems to the surrounding inhabitants, due to continuous passage of heavy waste trucks. The political and social claims that have followed have compelled the Public Authority to close the landfill in a very short time. For this reason, a fast and safe solution has been requested.

Wastes were provisionally covered with about 1.00 m gravel and with a thin LDPE geomembrane. The steepness and the length of the slopes (up to 38° and up to 35 m long) made it impossible to substitute the geomembrane with 1.00 clay, as requested by the regional law. The solution, designed with the approval of the local authorities, foresaw the removal of the existing membrane, and the use of a draining geocomposite, connected with a plastic pipes system, for gas collection.

4.1 Design and materials selection

GCL

The selected material for the lining shall have a low permeability and a good tensile resistance. Stitching shall not be continuous, to avoid that an accidental tear can propagate progressively to the whole GCL length.

The product selected on the base of these criteria is made up of two 150 g/m^2 woven geotextiles, which contain natural sodium bentonite (5 kg/m^2 minimum): it guarantees a permeability coefficient $k \leq 1x10^{-11}$ m/s. Since 1.00 m clay can provide a permeability $k = 1x10^{-9}$ m/s, this GCL is perfectly suitable, according to Italian law.

The two woven geotextiles are connected with diamond shaped polypropylene loop stitching, all separated and independent from each other. In this way any tear cannot propagate, but remains confined to the loop where it occurs. Direct shear tests, performed at a nominal pressure of 55 kPa, provided an equivalent internal friction angle of 36°. The tensile strength of this GCL is equal to 18 kN/m.

The GCL installation was followed by the placing of a drainage geocomposite, having also the function of protecting the GCL against damage by the cover soil.

Drainage geocomposite

The drainage geocomposite shall be selected in order to be able to discharge the flux produced by the rainfall infiltrating through the cover soil. The rainfall intensity shall be determined as having a "return time" of 10 years; when this intensity is known, it is possible to evaluate the actual input flow per unit area into the drainage geocomposite, through a water balance where evapo-transpiration, surface run-off and soil retention are considered. From experimental surveys in several urban landfills, the coefficient of infiltration to the drainage system results in the range of 0.20 ÷ 0.35.

Since the infiltrated water sums up along the slope to give the maximum flux at the bottom, then the worst case is obviously given by the flattest and longest slope of the landfill capping. In this case this resulted to be a single slope, between the berms, with 19° inclination and 21 m length.

The design rainfall intensity was determined on the base of the statistical coefficients for the rainfall in the area around Milano, and for a rainfall duration of 0.70 hours. In fact the short and intense rainfalls are the worst case, since they provide the maximum instant flow. After performing all the calculations, the design flux for the geocomposite resulted to be: $Q_r = 1.07 \times 10^{-4}$ m^3/sec/m.

Based on the pressure applied by the cover soil, equal to 3 kPa, it was chosen a geocomposite whose flow rate Q_g was much higher than the required one, as shown in Fig. 2.

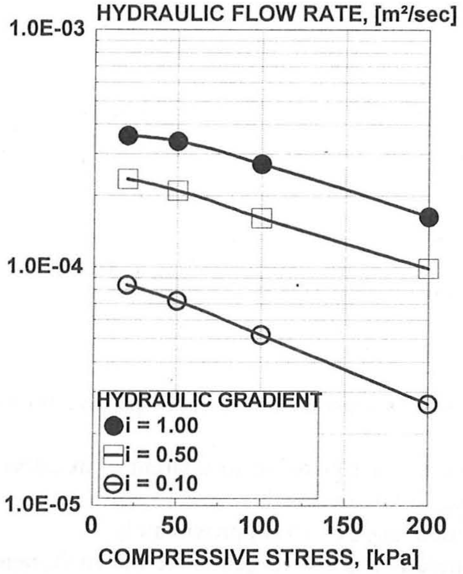

Fig. 2: Flow rate diagram for the geocomposite

The draining-lining package was fixed to the soil by mean of galvanised steel nails, 0.50 m long, spaced 2.00 m in staggered pattern. After placement of the entire package, the GCL was wetted. Finally, anchorage of topsoil (0.30 m) was provided by a reinforced geomat.

Reinforced geomat

The peculiarities of this project, with steep slopes and minimal space for any anchorage, suggested the use of a reinforced geomat made up of the mechanical coupling of a high strength geogrid with a geomat. This kind of product ensures an optimal distribution of the stress state and, at the same time, prevents the danger of topsoil sliding.

The mechanical properties of such product are listed in Table 1.

Tab..1: Reinforced geomat characteristics

Characteristic	**Value**	
Unit weight	675	g/m²
Nominal thickness at 2 kPa	17	mm
Tensile strength (machine direction)	110	kN/m
Strain at peak (machine direction)	10	%
Tensile strength (transversal direction)	30	kN/m
Strain at peak (transversal direction)	8	%

4.2 Stability analysis

The capping system is subject to a set of forces which, if not in static equilibrium, would trigger the sliding of the geosynthetics layers and/or of the topsoil. The free-body diagram for this problem is shown in Fig. 3.

The active force, that is the destabilising one, having direction tangent to the slope and downward is the component along the slope of the weight W of the soil block, given by:

$$W = t \cdot L \cdot \gamma$$

where: t = thickness of the topsoil
L = slope length
γ = unit weight of the saturated topsoil

The component F_S along the slope is:

$$F_s = W \cdot sin\beta$$

where: β = slope angle.

The resisting forces are: the friction force R at the geocomposite - topsoil interface; the passive thrust at the toe; the strength of the reinforcement R_g.
The passive thrust at the toe has not been considered, since it's not possible to guarantee an adequate compaction and density of this soil; this choice is, in any case, in favour of safety.
As already said, the geocomposite - GCL interface has a friction angle of 10° approximately.
It is evident that this is the critical interface: this friction angle is too low to guarantee the anchorage of the geosynthetic layers just along the intermediate berm without the excavation of a deep anchoring trench. But if we can assume that the GCL and the draining geocomposites are solidal and will deform or move together, then the top geocomposite - topsoil interface becomes the critical one, with a friction angle equal or lower than the friction angle of the topsoil itself.
The solidarity among GCL and geocomposites has been ensured by fixing all the three layers to the subgrade by means of long nails with large flat caps, passing through all the three geosynthetics and entering into the subgrade for at least 450 mm. The self sealing capacity of the GCL guarantees anyway the water tightness of the liner; in fact, thanks to its property, the bentonite will immediately seal the hole produced by the nail.
The nails has been designed with a 2.00 m spacing, in staggered pattern.
The friction coefficient along the slope has been reduced to 1/3 to take into account the low pressure produced by the topsoil.
Along the berms, instead, it was possible to excavate an anchoring trench (0,50 m x 0,50 m section) and to overfill it with a 1.0 m thick layer of well compacted granular soil, able, with its weight, to anchor the GCL and the draining and reinforcing geosynthetics.
The stability analysis has taken into account the fact that the granular soil on the berms has been placed only up to 1.00 m distance from the slope edge.
Given these assumptions, it is possible to calculate the required allowable tensile strength for the reinforcement, in order to ensure an adequate Factor of Safety FS:

$$FS = \frac{F_{resistant}}{F_{active}} = \frac{R + R_g}{F_s}$$

$$R_g = FS \cdot F_s - R$$

The allowable tensile strength of the reinforcement has been assumed equal to the strength at 2% elongation, obtained from its tensile - elongation curve from wide width tensile tests.
Finally the stability analysis for the anchorage length of the reinforcement has been performed by comparing the real force expected in the reinforcement (that is the one calculated without applying any

FS) with the anchorage resistance developed in the trench. The ratio of the two forces provides the Factor of Safety for the anchorage.

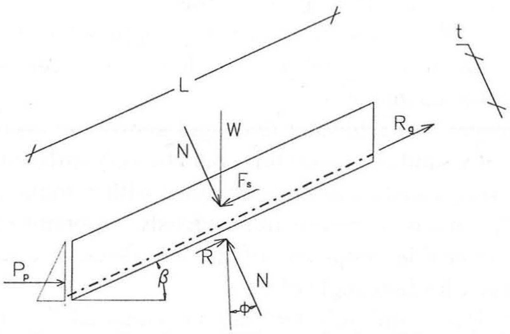

Fig.3: Free body diagram for the stability analysis of the capping system:
L = slope length; t = topsoil thickness; W = topsoil weight; N = component of W normal to the slope; F_S = component of W along the slope; PP = passive thrust at the toe; R_g = strength of the reinforcement; ϕ = friction angle of the critical interface; β = slope angle.

4.3 Final layout

Due to all these technical considerations above explained, the final layout of the capping system had to include details of the anchoring of the geosynthetics layers along the slopes and in the trenches, where the continuity of the GCL waterproofing had to be ensured. Fig. 4 shows the cross section and construction details provided in the final layout.

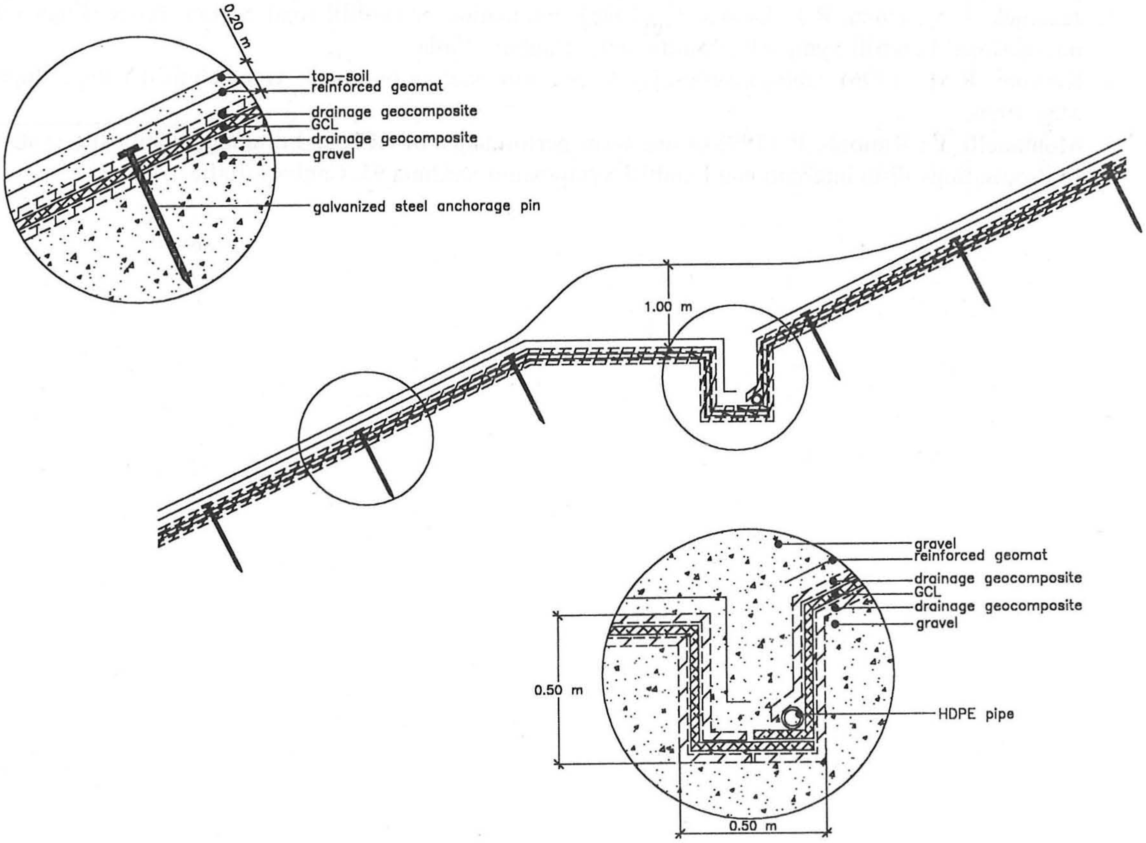

Fig. 4: cross section of the capping system

5. CONCLUSIONS

From the example shown, it is possible to draw the following considerations:
1) GCLs can be successfully used, even if with some precautions, as a capping waterproofing layer. To reduce the tensile stresses that the high shear forces could produce, however, it can be useful to add a proper reinforcement layer (geogrid or reinforced geomat).
2) The use of geocomposites (both for biogas and rainwater drainage) allows the capping of even very steep slopes. With natural materials (typically sand or gravel) this could be very difficult.
3) The anchorage system for the lining-drainage system must be designed with extreme care.
4) The knowledge of the real interface frictional behaviour is tremendously important in the analysis of a landfill capping stability. If no data are available about one of the interfaces, it could be possible to consider this as the critical one, and assume a friction angle of 0°.
5) Drainage geocomposites, properly designed and selected, are fundamental for providing positive drainage of gas and water, by allowing a proper Factor of Safety versus the maximum expected flux along the capped slope.

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