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Geosynthetics in French landfills: Particular geotechnical aspects

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ABSTRACT : Geosynthetics are more and more used in landfills but their application induces a new concept of the correlative earthworks and bring new geotechnical problems for the designer.
Three typical french recent case histories of landfills are presented, illustrating some specific engineering aspects of use of geosynthetics.

1 INTRODUCTION : GEOSYNTHETICS IN MODERN LANDFILLS

Landfills have become real civil engineering structures, wich are highly technical in design and require the expert skills of engineers. All the industrialised countries are working toward adopting new regulations, and consequently new concepts for modern landfills. Geosynthetics have an important role to play in these concepts and correlatively, new geotechnical interesting problems arise. The next chapters present some recent case histories where the use of geosynthetics, in accordance with the new french regulation, confronts the designer with a necessary new geotechnical approach.

We can summarize below the different functions possibly sustained by the different families of geosynthetics in a modern landfill :

- Sealing systems for bottom, slope and cap barriers include in association with a mineral clay layer (natural geological formation or additional compacted layer) a flexible membrane liner (geomembrane or geocomposite clay liner). Mineral and synthetic layers have really be thought of as complementary.
- The geosynthetics liners are mechanically attractive, on account of the possibility to be placed on steep slopes and to withstand large extension strains.
- It is worth noting that a barrier of a landfill has not only the role of preventing external water from penetrating the landfill and waste leachate from reaching the surrounding soil but it also has a drainage function : it collects leachates (slopes and bottom) and gases (cap). For drainage systems, specific geosynthetics are proposed, geonet for drainage, geotextiles for filters. Unlike mineral drainage and filter layers constituted of cohesionless soil, and with regard to their mechanical behaviour, they exhibit significant tensile strength.
- Finally, another interesting development for application of geosynthetics in landfills involves reinforcement of the waste so as to increase the slope of the stored waste and possibly facilitate architectural works once the landfill is closed or reinforcement of the external dikes of the landfill cells. Geotextiles and geogrids are used for this kind of application.

However, geosynthetics in landfill applications induce a new geotechnical design, related to interaction between geosynthetics and other landfill constitutive materials. This is illustrated bellow.

2 NEW CONCEPT OF LANDFILL CAP : CASE OF THE MENNEVILLE LANDFILL

The Menneville collective hazardous waste landfill has been opened in 1977 in the north of France, in an old clay quarry.

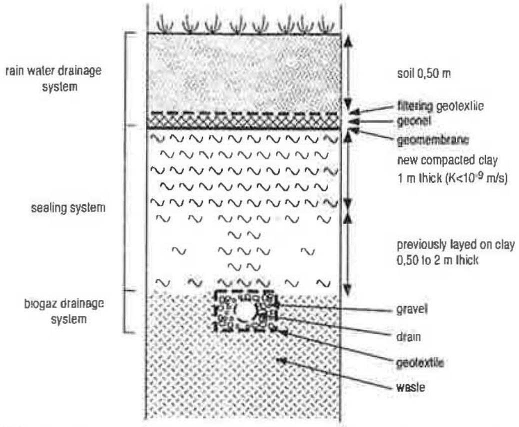

Fig 1: Menneville storage: Proposed capping system (schematic cross section)

Municipal Solid Waste (MSW av. 30 % weight) and hazardous waste (av. 70 % weight) from various industries have been stored until 1994, representing a total volume of 1.000.000 m^3.

In 1994, a lined landfill cap enforced by the new regulation instead of the clay cover previously layed on, has been installed.

The regulations concerning site redevelopment require (french ministerial decree, 1992 ; Gisbert, 1993 ; Bloquet et al 1995) :

- complete insulation of the site from rainwater penetration
- harmony of the site with its surroundings
- long term compatibility of the area with the presence of waste
- practicable control of emissions into the environment.

To comply with current french regulation, the following scheme was approved (fig.1):

The system was designed with the following factors in mind :

- Climatic factors :

For the detailled design of the drainage system, water supply was estimated from the HELP model on the basis of the data of the last ten years. The greenery planting layer was designed in order to avoid dammages due to frost.

- Biogas analysis :

The quality and composition of the biogas were measured in order to calculate the dimensions of the trench drains and to ensure that the site was completely degassed by pumping.

- Differential and/or localised subsidence :

The sealing and drainage system had to remain intact regardless of differential settlement and to

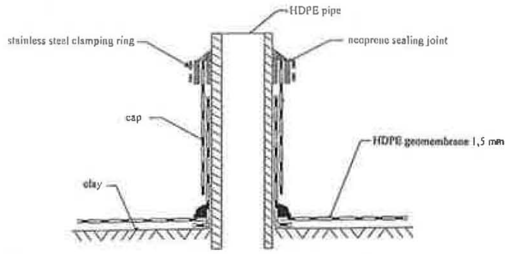

Fig. 2 : Cross section of the sealing system for biogas wellheads

resist erosion. Level markers were installed to measure the risk of differential settlement. Results have shown differential subsidence in the landfill of 0 to 15 cm per year, depending on the age of the storage cells.Given this subsidence, the biogas recovery wells should be able to be inserted easily at any point in the cover. A specific design has been retained (see fig. 2).

In accordance with the above obligations a VLDPE-type geomembrane was recommended. Even if the design specified the use of a 1 mm thick VLDPE geomembrane considering its mechanical behaviour (no yield pick), all the contractors proposed the use of a 1,5 mm thick HDPE geomembrane arguing for its better welding behaviour, durability and from their own experience.

- Material permeability studies were carried out on the periphery to ensure impermeability between the cover to be laid and the edges of the site.
- Cover stability tests : With regard to the surface stability of the cover, the most problematic efficient interface is the one between the geomembrane and the drainage geonet. An analysis was carried out considering the stability of an infinite slope which was justified, given the scale of the site (70.000 m²). The safety factor of 1.5 required a minimum friction angle of 17° between the geomembrane and the geosynthetics used for drainage, with a normal stress factor of 10 to 20 kPa (Giroud 94, Giroud and Beech, 89, Williams and Houlitian, 86 ; Lopes et al, 93).
- Land survey : This study covered the landscape and the industrial tradition of the area including well-established storage methods and was taken into consideration for design purposes.

The construction of this landfill cover was accompanied by a quality assurance programme especially prepared for this project.The programme took into consideration all the components of the sealing system and determined the scope of quality assurance for internal and external supervision as well as the quality requirements for the individual components.

3 WASTE REINFORCEMENT BY GEOTEXTILES TO INCREASE STABILITY AND STORAGE CAPACITY : CASE OF THE TORCY LANDFILL

One type of failures, the global slip along the lining and the drainage systems, was observed on several sites, landfills or not. It is very important to be aware of this specific aspect, because lining and drainage systems often introduce low friction interfaces due to the superposition of geosynthetics layers. If this phenomenon is evident along embankments, it can also occur even if the liner slope is small, for exemple at the bottom of the landfill.

A numerical study (Artières et al., 1994) was undertaken to evaluate the influence of several parameters (bottom slope, height of waste, type of friction interface, water level in the waste) on the stability of the waste over a typical lining system : [clay - HDPE geomembrane - nonwoven needlepunched geotextile - gravel - waste]. It shows that :a) the most critical interface corresponds to the lower friction angle (here between geomembrane and geotextile) ; b) the efficiency of the drainage over the geomembrane is of great importance on the stability ; c) a lower slope of waste increases the stability of the embankment, but its influence is rather low. The use of geotextiles to reinforce the body of waste either near the lining system, or inside the waste is a solution which allows on one hand an increase of the global stability and on the other hand, a design of the landfill closer to the specific constraints of the site : better adjustment to the local topography (variable slopes of the embankment are possible), increase of the stored waste for a given land area, etc...

This solution was designed in the case of the Torcy landfill. The bottom lining system is described in fig. 3. Due to local topography, the maximum height of waste is planed to be 40 m with an external slope of 45°. The slope of the lining system is 1 % in this direction. In the Torcy case, the more critical sliding surface passes through the waste and follow the lining system between the geomembrane and the geonet. The two materials have the lower interface friction angle of all the structure. The global tensile force which is necessary to mobilize in the geotextile reinforcement in order to obtain a safety factor of 1.2 is about 2800 kN for 1 m width of the embankment in the short term' case. The reinforcement structure designed with the CARTAGE program consists of 31 layers of high strength (200 kN/m) and high stiffness (1400 kN/m at break) geotextile. The geotextile is the association of a needle-punched nonwowen polypropylene geotextile, knitted with polypropylene yarns. The yarns give the tensile properties, when the non-woven placed above the yarns protects them against mechanical damage due puncturing by the waste or by the traffic. This particular point allows to reduce the safety factor on the product according to the french standardization on geotextiles for soil reinforcement. Polypropylene offers a good chemical compatibility geotextile-leachate, particularly at high pH values. Partial safety factors take into account durability and possible degradation of the product. It must be noticed that the assumptions on the waste shear characteristics ($c = 0$ kPa ; $\phi = 20°$; $\rho = 1$ t/m^3) were chosen on the safe side and induce a high level of reinforcement. More precise evaluation will certainly allows a reduction of the reinforcement costs, and will be more economic.

4 SLOPE STABILITY PROBLEM IN A SOLID WASTE LANDFILL

A slide of approximately 60.000 m^3 of municipal solid waste (fig. 4) occurred in a cell of a Class II municipal solid waste landfill site operated in accordance with french regulations regarding the use of a passive clay barrier and an impermeable geomembrane in the sealing-draining complex. A back analysis of the waste slide was carried out in order to determine the possible causes of the event and to learn from the experience.

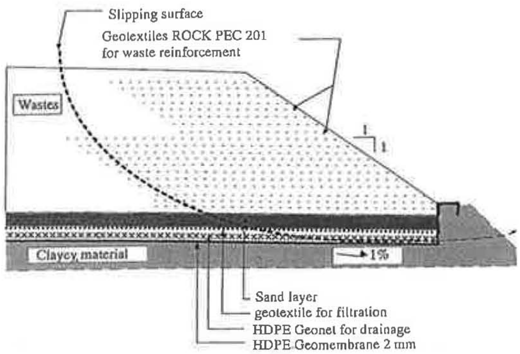

Fig. 3 : Cross section of the Torcy landfill

Fig. 4 : View towards the east of the waste slide

4.1 *The landfill site and the slide*

The development plans for the municipal solid waste landfill site, which lies at the bottom of a north-south dry valley terraced in chalk, called for the earthworks and the laying of the watertight barriers to be undertaken in two phases : the first phase, subject of the present analysis, was carried out in 1993 and involved 150.000 m3 of earthworks to construct an operational cell. The second phase, to complete the landfill site, involved 300.000 m^3 of earthworks and was programmed for the spring of 1994.

The first phase operational cell was prepared on the western side of the landfill site with a slope ratio of 2 (horizontal) in 1 (vertical). The sides and bottom were first covered by a passive barrier of at least 3 m of compacted imported clay, the compaction giving a permeability of less than 1.10^{-9} m/s. The active barrier, a 2 mm thick impermeable high-density polyethylene (HDPE) geomembrane separated from the clay substratum on the bottom of the cell by a heat-bonded geotextile with a surface density of 190 g/m², was then laid in December 1993 ; unfortunately during a very wet period (234 mm of rainfall during the month of installation). To ensure proper drainage of the waste, the geomembrane was covered with a layer of sand combined, on the slopes of the cell, with used tires placed directly on the geomembrane to protect it from damage during waste compaction (figure 5).

The cell was then commissioned for storing compacted municipal waste. When the waste slide occured, in July 1994, it lasted for two hours and was only halted by installing a toe ridge. At this time, the average thickness of the waste pile had reached 12-15 m, with a maximum of 20 m, and the

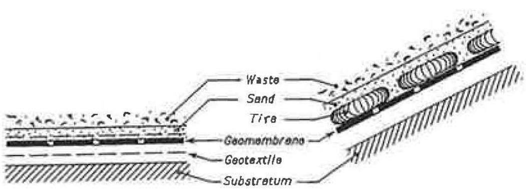

Fig. 5 : Diagram showing the principle of the sealing-draining complex

contractor was in the process of carrying out earthworks (second development phase) below the dikes of the operational cell.

Our observations at the site show that the waste slide occurred along the geomembrane/clay interface on the slope of the cell, and along the geotextile/clay interface on the bottom of the cell ; resumption of the phase 2 extension work has revealed that the geomembrane at the toe of the waste slide had remained attached to the body of waste. The geomembrane anchors were torn out over a 60 m length and the displacement at the top of the waste slide was between 5 and 6.70 m. Cracks were observed in the upper third of the waste slide, indicating that the body was under traction stress. The moisture content measured in a sample of clay from beneath the geomembrane at the toe of the waste slide was 5 to 9 % higher than the value obtained after the passive clay barrier compaction in the autumn of 1993.

4.2 *Stability back analysis*

The purpose of the back analysis was to establish the mechanisms that gave rise to the slide and from to this determine the modifications that need to be taken into account for the design and use of waste storage cells so as to limit the risk of further incidents. Having determined that the slide occurred along the clay/geomembrane and clay/geotextile (beneath the membrane) interfaces, parameter values for geosynthetics/clay interfaces were obtained from the literature (Table 1). We then asked the Geology and Mechanics Laboratory IRIGM, of University of Grenoble, to carry out a series of shear tests, which were done in a 30 x 30 cm box with the shear plane imposed along the clay/geosynthetics interface. Two series of tests were made : one using compacted clay with a natural moisture content and density close to the Proctor optimum ; the other using the same compacted clay after it had been immersed beneath

3 cm of water for 24 hours so that the surface was saturated.

The test results (Table 2) on the clay with a natural moisture content close to a Proctor optimum show slightly lower friction angles than those obtained from the literature and similar cohesions. Increasing the moisture content of the clay surface resulted, as would be expected, in a significant reduction of the strength of this clay/geosynthetics interface. The back analysis was carried out using a finite-difference model that enables 2D static simulation with large displacements. The plane of the slide is simulated by interfaces defined by the mechanical parameters of the waste slide. The Coulomb shear-strength criterion limits the shear force according to the following equation :

$F_s max = cL + \tan \phi \, F_n$

Where c = cohesion along the interface, L = the effective contact length, and ϕ = the friction angle of interface surfaces.

The analysis was initiated by supplying the model with the interface parameter values obtained from the literature, followed by those obtained from the laboratory tests. The parameters provided to the model for the different beds and interfaces based on the laboratory test results are given in Table 3 (short term characteristics).

Table 1 - Literature values of the clay/geosynthetics interface coefficients (Koerner 1990)

Geosynthetics/clay interface	**Cohesion c_u (kPa)**	**Friction angle ϕ°**
HDPE geomembrane/clay	14	15°
Heat-bonded geotextile/clay	14	15°

Table 2 - Test values of the clay/geosynthetics interface coefficients

Geosynthetics/clay interface	**Cohesion c_u (kPa)**	**Friction angle ϕ°**
Clay / HDPE geomembrane *moisture content 15 %*	14	8.7°
Clay / heat-bonded geotextile *moisture content 15 %*	16.8	10.7°
Clay / HDPE geomembrane *Saturated clay*	0.5	1 °
Clay / Heat-bonded geotextile *Saturated clay*	3.6	1.5°

Table 3 - Parameters used for the simulation

Material	**Volume weight γ (kN/m3)**	**Cohesion c_u (kPa)**	**Friction angle ϕ°**
Chalk (substratum)	20	20	35°
Gault Clay	16	28	22°
Stored waste	13	44	29°
Clay / Geotextile interface		3	1.5°
Clay / HDPE geomembrane interface		0.5	1°

The obtained simulation gives a slide with displacements of 6 m and craks in the topmost third of the slide, thus faithfully reproducing the observed slide. A parametric study on the influence of the different interface coefficients shows that the slide occured with a cohesion of less than 5 kPa and a geosynthetics/clay interface friction angle of less than 4°. The numerical calculations thus confirms that one of the factors causing the slide was a weakening of the geosynthetics/clays interface properties, which can be explained by the fact that the geosynthetics were laid on a clay substratum saturated by the heavy rains of December 1993.

4.3 *Conclusions and recommandations*

It would appear that the waste slide resulted from a combination of factors as follow :

- the waste pile was too thick ;
- the mechanical parameters really mobilized along the potential slide plane appeared to be lower than the values taken into account for the design : the geosynthetics (geotextile and geomembrane) having been laid on a bed of clay saturated by heavy rains ;
- a mass of waste physically pulling the geomembrane through the drainage layer of tires and sand.

Based on this back analysis of the waste slide we propose a few recommendations for the future :

- The design of a landfill site and the plans for its utilization should include interface stability calculations and a higher safety margin, considering that our knowledge of these parameters is still incomplete.
- The waste should be dumped symmetrically with low slopes so that the waste pile is self stabilizing.

- When laying the impermeable membrane, both the site contractor and membrane subcontractor should check the external parameters such as the moisture content of the substratum and the temperature because these parameters can appreciably modify the initial design factors. Such checks should also be included in the quality assurance plans.
- If the use of tires is considered as a safeguard against the impermeable geomembrane puncturing, it must be realized that these tires could favor the transfer of stress between the waste pile and the geomembrane. This risk could be reduced either by installing a device (e.g. geotextile) to reduce the friction angle of the tire/geomembrane (e.g. geotextile) interface or by using a reinforcing geosynthetics capable of supporting the transmitted pull force.
- The slopes and intermediate berms should be calculated with an adequate safety factor to ensure stability.

REFERENCES

Artières O, Delmas Ph., Correnoz M. and Oberti O. 1994, " Stability of wastes on lining systems " Analysis and design. *Proc. of 1st Int. Cong. on Envir. Geotechnics, ISSMFE, Edmonton, Canada.*

Bloquet C, Simond J.J., Gisbert T and Matichard Y., " Top cover system in an hazardous waste landfill ", *Sardinia 95, Fifth international landfill Symposium, S. Margherita di Pula, Cagliari, Italy*, 2-6 october 1995, p. 550-554.

Gisbert T. 1993, " Present and potential uses of geosynthetic materials for industrial waste disposal facilities ", *Geoconfine 93, vol. 1, p. 201-206.*

Giroud, J.P. and Beech J.F. 1989, " Stability of Soil Layers on Geosynthetic Lining Systems", *Proceedings of Geosynthetics'89 Conference, San Diego, USA.*

Giroud, J.P. 1994, " Cell and Liner System Detailled Design ", Landfill Design Services, *Treeo Center, University of Florida, Vol. 4.*

Gourc, J.P. 1996, "Geosynthetics and environmental engineering" , Mercer Lecture, XII *Int. Conf. on Soil Mechanics and Foundation Engineering, Vol. 6. + CD Rom* (to release).

Koerner, R.M. 1990, " Designing with Geosynthetics ", *Prentice-Hall, Englewood Cliffs, N.J., 2nd Edition, 652 p.*

Lopes R.F., Smolkin P.A. and Lefevre P.J. 1993, " Geosynthetics Interface Friction : a challenge for Generic Design and Specification ", *Proceedings Geosynthetics'93, Vancouver, Canada, p. 1259-1272.*

Ministerial decree of 18 december 1992 (modified on 18 february 1994) relatived to the storage of hazardous final waste products and stabilized products.

Ouvry, J.F. ; Gisbert, T. and Rouvreau, L. 1995, "Back analysis of a slide in a waste storage centre ", *Rencontres'95, Beaune (France) ; 27,28th Sept. 1995, p. 148-152.*

Williams N.D. and Houlitian M. 1986, "Evaluation of friction coefficients between geomembranes Geotextiles and related Products", *Proceedings of the third International Conference on Geotextiles, Vienna, Austria, p. 891-896.*