Geosynthetics, J. Kuwano & J. Koseki (eds)

Capping systems for landfills in an active seismic area: Case history of Catania (Italy) old MSW landfill

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Keywords: landfill, seismic active area, capping systems, particular boundary condition, geosynthetics solutions

ABSTRACT: A specific design procedure must be used to design capping for landfills when particular boundary conditions are evident. The recent Italian landfill laws cannot take into account the possibility to use alternative materials for capping system, imposing a certain number of soil layers, with particular characteristics, to obtain the final cover. The experiences and many applications have show that particular boundary and geometry conditions of the landfill, impose an alternative design of the capping because the natural materials are not able to carry out their function and instability problems can occur. Many others problems are evident if the landfill is located in an active seismic area where the horizontal acceleration produce a further instability factor inside the system. An MSW landfill located near Catania (Italy) is a clear example of these problems. For this landfill very high inclination of lateral facing of the slopes are evident, up to 42 degrees, thus the capping design cannot be made using a classical gravel-clay layer system. In this paper was proposed an alternative capping system for Catania landfill, using geosynthetics materials, for biogas migration, clay barrier and rain drainage. All stability analyses were conducted in dynamic conditions and dynamic interface resistance between materials were considered. The dynamic response of the capping system was obtained by calculating the local seismic response using, as bedrock earthquake, the scaled E-W component of the Catania earthquake recoded on December, 1990. All analysis was conducted using both a pseudo-static approach and a finite difference modelling, using Flac 2D software.

1 INTRODUCTION

Recent advances in geotechnical engineering together with the continuous awareness of environmental protection, have lead to the improvement of geosynthetics design and application. Geosynthetics are extensively used in the cover and bottom barrier systems of new landfills.

The study conducted by the authors regarding the dynamic response of the MSW Catania landfill and the realization of an alternative capping system for the landfill, using geosynthetics materials, for drainage, gas migration and sealing, due to the particular geometry of the system. Similar applications were used by many authors in various landfill that have characteristics similar to Catania landfill. Other geosynthetics capping system has been used in Italy and in many country, but only in a few cases the landfill site was located in a seismic active area such as Catania landfill (Maugeri and Pinto, 2005). This particular boundary condition produce a further design problem due, especially, to the response of landfill and to the dynamic friction behaviour between geosynthetics capping layers. In this paper an alternative capping solution for Catania Old MSW landfill was proposed, using geosynthetics materials rather than soil layers as prescribed to the Italian law dispositions.

2 SITE AND WASTE CHARACTERIZATION, AND GEOSYNTHETICS PROPERTIES

2.1 *Geological and geotechnical characterization*

Catania landfill site is located along the Sicily East cost in the South of Catania. The landfill extension is approximately 300,000 square meters. Inside this area various waste landfills are located such as the old MSW described in this paper. This landfill, in particular, has an extension of about 150,000 square meters with a maximum difference of level of about 55 meters and maximum gradient of lateral facings equal to 42°. Figure 1 show a planimetric view of

landfill site in which is evidenced the old MSW extensions. The site area is geologically located along the northern border of Ibleo plateau and is placed inside the hydrographical system of Simeto river. Figure 2 is a photo of the landfill showing the inclinations of the outer surface

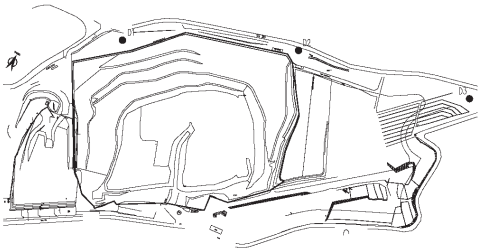

Figure 1. A planimetrical view of landfill site in which is evidenced the old MSW extensions.

Figure 2. A photo of the old MSW Catania landfill.

Soil characteristics of the MSW foundation area, is a succession of typical limestone and sands with a large component of volcanic rocks, with a very high density. The geotechnical characterization of landfill soil foundation was conducted through laboratory tests performed on a certain number of soil samples. The results of these tests were summarized in Table 1.

Table 1. Laboratory results of subsoil landfill investigation.

W_n = 21.50%	W_l = 35.50%	e = 0.712
I_p = 13.70%	I_c > 1	W_{sat} = 19.23 kN/m^3
S_r = 82%		W_{dry} = 15.83 kN/m^3

2.2 *Waste characterization*

Geotechnical waste characterization is a very uncertain factor when a stability analysis must be conducted to evaluate the dynamic response of the entire system soil-waste-capping.

Recent advances have occurred in waste management due to geotechnical study about the behaviour of waste, permitted to classify the waste in two category: waste that can be compared to soil behaviour, such as industrial one and waste that can't be compared to the soil such as municipal solid waste.

For the second classification, that is the most common, the stability analysis is affected by the uncertainties in the mechanical parameters, such as internal friction angle, cohesion and Young module, which are very difficult to determinate through laboratory or in situ tests.

Numerous investigations of the waste behaviour have been conducted experimentally (e.g., Grisolia et al. 1992, Manassero and Pasqualini 1993, Van Impe and Bouazza 1996, Kavazanjian 2001, Machado et al. 2002, Carruba 2003), obtaining the following typical correlations reported in graphic form (Figure 3).

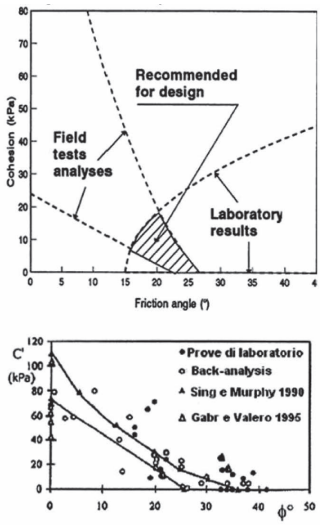

Figure 3. Typical correlations for waste parameters.

The results obtained from the previous tests shown that shear failure did n (Figure 3).ot occur. This behaviour is due to the waste composition which can be assimilated to a reinforced material due to the fibrous element contained inside (paper, plastics and textiles materials, wood) and the resistance value is time dependant.

No laboratory or in situ tests were performed at the Catania landfill wastes. Their typical composition associated to a back analysis conducted during wastes awarding, allow to evaluate the geotechnical parameter, reported in the table 2. With the purpose to describe the possible landfill behaviour during seismic condition a parametric analysis was conducted in which the waste parameter assumed the values reported in Table 3 for dry condition and in Table 4 for partial saturated condition.

2.3 *Geosynthetics dynamic friction determination*

From a mechanical point of view, a knowledge of the frictional behaviour in static and dynamic condition between the geosynthetics, is very important for an

Table 2. Typical waste parameter for the stability analysis.

E = 2000 kPa	ν = 0.37	φ′ = 27-35°
c′ = 10-15 kPa	γ_d = 1 kN/m^3	γ_{sat} = 1,4 kN/m^3
w = 25%	C_u = 0	

Table 3. Waste parameter for dry condition.

	E [Kpa]	c [Kpa]	φ [°]	F_{oS}
A1	2000	10	27	**1,28**
A2	2000	20	27	**1,57**
A3	2000	30	27	**1,81**
A4	2000	10	33	**1,54**
A5	2000	10	40	**1,87**
A6	5000	10	27	**1,28**
A7	10000	10	27	**1,28**

Table 4. Waste parameter for partial saturated condition.

	E [Kpa]	c [Kpa]	φ [°]	F_{oS}
B1	2000	10	27	**1,10**
B2	2000	20	27	**1,40**
B3	2000	30	27	**1,66**
B4	2000	10	33	**1,31**
B5	2000	10	40	**1,58**
B6	5000	10	27	**1,10**
B7	10000	10	27	**1,10**

assessment of the stability of the inclined lining systems. A certain number of large scale shaking table tests were carried out at University of Catania using geomembrane/ geotextiles, geomembrane/GCL and geocomposites/ GCL interfaces and GCL/soil interface. The maximum amplitude and frequency content of sinusoidal input excitations are investigated in terms of acceleration transfer through the interface and geosynthetic/ geosynthetic relative displacement. Finally a real time-history acceleration regarding the 13 December, 1990, Catania earthquake is used as input excitation. Until no table-geosynthetic block relative displacement occurs, i.e. no slippage occurs, the block moves together with the shaking table. When the interface friction is achieved a relative displacement occurs.

According to the Coulomb failure mechanism at the geosynthetic/geosynthetic interface, the minimum acceleration, which leads to a relative displacement, named also "critical acceleration" ($a_{crit.}$), gives the dynamic friction coefficient (tan ϕ_{dyn}) of the geosynthetic/ geosynthetic interface:

$$\tan \phi_{dyn} = \frac{a_{crit}}{g} \quad (1)$$

where g = acceleration due to gravity.

For some tests, especially when geocomposites/ GCL were used, the accumulation of the relative displacement cannot be evaluated with the typical Coulomb frictional contact theory; a dynamic analysis must be performed taking into account the elasto-visco-plastic behaviour of the interfaces. A very high friction has been evaluated.

Analyzing the typical results obtained for the interfaces investigated it can be underline that very low dynamic friction angle occur when PEAD (Polietilen High Density) geomembrane was used, with the consequence that this geosynthetics must be used carefully in inclined cover design and must be associated to a very efficient anchorage system to prevent sliding movement just in static condition.

3 STABILTY AND DEFORMATION ANALISYS

With the purpose to design the most appropriate capping system for the examined landfill, all of the possible failure modes were investigated such as lateral facing stability, geosynthetics anchorage pull-out, waste stability, sliding failure mode of waste on geosynthetics, soil stability above capping system.

The dynamic response for the site was determined through the calculation of the acceleration amplification as an effect of the intermediate soils deformations, starting from to an accelerometric data at the bedrock as a known value. The scaled accelerometric signal recorded during Catania earthquake on December 1990 was used in this case.

Figure 4 shows the reported accelerometric components of the Catania earthquake. The local seismic response were determined by associating every layer crossed by a seismic shear wave to an appropriate wave velocity. In table 5 the assigned values are reported. For each analysis the deformation, displacement vectors, vertical and horizontal displacements are reported. In Figure 5 were reported the results of the pseudo static analysis conducted applying the Janbu limit equilibrium method. Figure 5b reported the partial saturated analysis that take into account the possibility of a leachate drainage system failure. The safety factors for the examined systems is equal to 1.55 and 1.33 respectively.

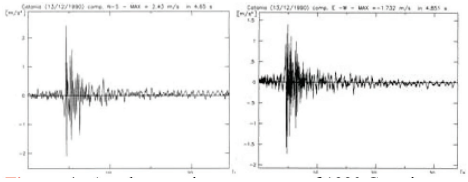

Figure 4. Accelerometric components of 1990 Catania earthquake.

Table 5. Soil layer and relative shear waves velocity.

Soil	V_s (m/s)
Waste	200
Loose tout venant soil	100
Silty sand with pebbles and gravel	350
Bedrock	700

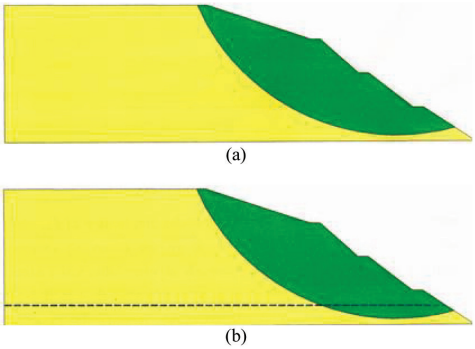

Figure 5. Results of the pseudostatic analysis conducted applying the Janbu limit equilibrium method.

The dynamic response of old MSW Catania landfill was investigate also through a parametric analysis using a finite difference method in which the parameters reported in the previous Table 3 and Table 4 are used. In the following Figures 6 are reported the results obtained for the analyses named A1, A6, B1 that is for the minimum value obtained for the safety factor. For each analyses were reported the deformations, the displacement vectors, vertical and horizontal displacements.

From the previous Figures it can be observed that a failure surface through the displacements vectors is associated to large displacements due to the waste composition and to the relative geotechnical parameters. These value compare well with those computed by others similar analyses and with those observed from landfill periodic check through topographic survey.

4 LANDFILL CAPPING SYSTEM

4.1 *Capping system with natural soils*

The previous stability analyses give important information about the capping system to use. A typical cover design, in according to the Italian law in application to the Council of the European Union Directive 1999/31/CE, establish a sequence of soil natural layers, with various functions, and each layer must be characterized by a given value of the permeability coefficient. The typical cover system is show in Figure 7. From Figure 7 it can be observed that the system proposed is not always applicable, due to the mechanical properties of soil layer which not take into account the possibility of a high gradient of lateral landfill facing. A simple stability analysis of each layer at residual state, imposing a maximum value of residual friction angle incompatible with the inclination of landfill slope.

As an example, the residual friction angle typical value, for the mineral barrier, is equal to 18°. The

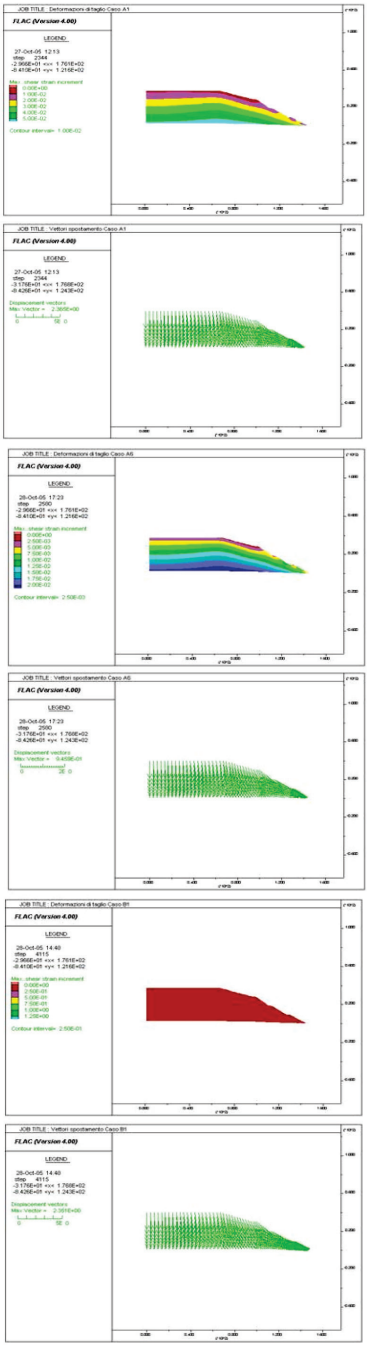

Figure 6. Finite difference analyses results.

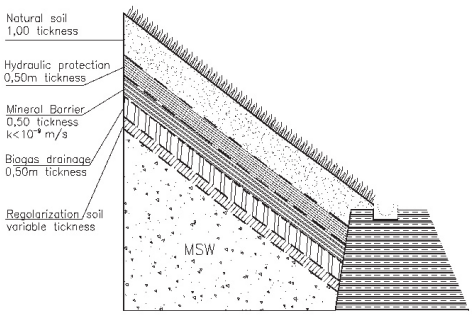

Figure 7. A typical final cover in according to the Italian law.

safety factor for this layer can be calculated as:

$$F_s = \frac{\tan \varphi_r}{\tan \beta} \tag{2}$$

Appling the previous equation (2) to the Catania landfill, the safety factor, for the mineral layer, will be equal to 0.40. Moreover the realization of natural soil layer above landfill with very high inclination respect the horizontal, is very difficult under the point of view of laying without a real warranty that the prescribed permeability have to be reached.

Finally, this cover solution not compare well with the deformation obtained by the finite difference analysis in seismic condition due to a reduction of shear resistance.

The previous cover can be improved if the single layer have to be reinforced with a geogrid with the purpose to increment the shear strength.

No detailed analyses were conducted for this solution due to a clear economic problem and because the previous laying problem are the same.

4.2 *Capping system with geomembrane*

Many final covers are completed using a PEAD geomembrane with the purpose to eliminate the water infiltrations and an alternative to the mineral soil with very low permeability. Geomembrane application allows reduction in the oxygen flux through the cover barrier and reduce the percolation effects (Kim and Benson 1999).

This particular geosynthetic offers the possibility to obtain a laying also for very inclined lateral landfill facing, using an appropriate anchorage to prevent sliding effects due to the low friction angle imposed by geomembrane surface (a minimum value in seismic condition of about 8°). In seismic condition this problem is more evident especially if it is associated to a high level deformation that can produce a rupture along the welding.

Moreover documented cases in which the inertial effects, due to the seismic load, had produced a global sliding of the natural soil placed above the geomembrane with a compromising of the hydraulic protection system.

To prevent failure of the final cover a geogrid composite capping system can be used together to the PEAD geomembrane in order to increase the resistance along the sliding direction and with the purpose to transfer to the geogrids the inertial forces induced by dynamic load.

The improved adhesion surfaces geomembrane to increment the interface friction can be also used.

4.3 *Composite capping system*

Use of geosynthetics to obtain composite final landfill cover shows a very high performance in order to reduce the percolation, the water infiltration and assure a very high stability for many boundary condition and also under a seismic event. Italian law does not take into account, for the capping system, the possibility to use, with an appropriate hydraulic equivalence, a composite system, with the consequence that many real cases, such as old Catania landfill, problems are experienced for the final cover design. These limitations appeared clearly when the slopes inclination associated to a particular external load conditions, make it possible to carried out the landfill capping. Figure 8 shown the composite cover proposed for the old MSW Catania landfill. In this proposed system, a GCL with hydraulic conductibility coefficient equal to the prescribed values . The stability analyses conducted on this composite capping, shown an increment of the stability factor due to the strong reduction of inertial forces as a consequence to the soils mass. This solution have a good performance under seismic condition especially because the deformation computed with the finite elements analysis can be considered compatible with those of the geosynthetic layers. The soil mass of the natural soil produce an inertial force, under dynamic load, entirely distributed to the geosynthetics surfaces without compromise the internal stability between the single layer. Finally, the geosynthetics anchorage system must take into account the effects described. The required length for a geosynthetic able to ensure a good safety factor to pull-out effects and, consequently, sliding failure mode can be expressed as follow:

$$T_t = F_{\text{soil}} + F_{\text{soil–geos}} + 2F_{\text{fric}} - F_i \tag{3}$$

where T_t is the geosynthetic limit traction strength, $F_{\text{soil-geos}}$ is the friction contribution between soil and geosynthetic in the horizontal direction, F_{fric} is the contribution due to vertical friction inside the soil cutting, and F_i is the contribution of the inertial forces due to the soil mass placed above the geosynthetic and proportional to the acceleration level. Finally, due to the very high lateral landfill facing gradient (42°) a reinforced GCL must be used as water barrier in order to improve the internal shear resistance.

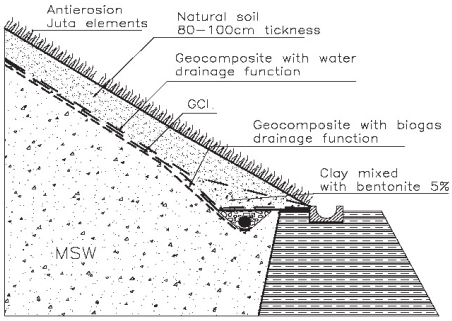

Figure 8. Composite cover proposed for the old MSW Catania landfill.

5 CONCLUSION

In this paper was reported the proposed Catania old MSW landfill cover barrier. Some stability analyses were conducted, using pseudo-static and finite elements method. The dynamic response of landfill system shown a good performance under dynamic load with moderate deformations and displacements. The analyses of original design, have underlined that the instability phenomena are evident when mineral natural soils were used due to the increment of the inertial forces as a consequence of the earthquake. A composite capping, finally, was proposed showing the good performance of the geosynthetic used, showing a good adaptability to the permanent deformations induced by the dynamic load. Moreover an economical improvement are ensured when a composite final landfill cover was chosen.

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