Slope stabilization with geosynthetics in the construction of a MSW landfill

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ABSTRACT: A slope with a height of more than 70 m had to be stabilized by means of significant interventions of reinforcement, lining and monitoring, in order to realize a MSW landfill in a hilly area of Tuscany (Italy). Complex geotechnical and geomorphologic problems were faced in order to define the appropriate works, owing to the steepness of the slope (about 90°), to the slope lining, to the overall stability, and to the narrow space of maneuver. The site geology is characterized by the presence of impervious Pliocene clay with poorly permeable sandy intercalation. The design solution foresaw the construction of reinforced earth walls, alternated to stepped terraces. Cement-bentonite slurry diaphragms, of more than 25 m depth, had to be realized on the terraces to intercept the permeable sandy layers and to isolate the MSW from the sandy horizons.

1 CHARACTERISTICS OF THE SITE AND OF THE WORK

The landfill is located in a hilly area of Tuscany (Italy), of significant landscape value, and represent the downstream expansion of an old plant.

The scheduled volume of the new basin is of 700.000 m^3, allowing the disposal of 435.000 tons of MSW.

The landfill rests on a Pliocene formation made up of clay whit thin alternations of sand. The stratigraphical sequence is characterized by a thick succession of impervious Pliocene clay and clayey silt with sub-horizontal setting, containing frequent intercalation of permeable sandy and pebbly levels, from continuos to lens-shaped.

The thickness of the sandy levels varies from point to point and from one level to another, reaching a maximum of about 10 meters.

The clayey materials are characterized by low plasticity and very high degree of consolidation; the loose lithotypes, whose grain size varies from that of silty sand to that of medium sand with frequent pebbly and conglomerate levels, are usually very dense and compacted.

The design solution foresaw the construction of reinforced earth walls in order to solve complex geotechnical and geomorphologic problems: a slope with a height of more than 70 meters had to be stabilized by construction of reinforced earth walls alternated to stepped terraces (Figure 1, Figure 2).

The design foresaw the construction of cut-off diaphragms due to the presence of permeable sandy intercalation within the clayey sequence: cement-bentonite slurry diaphragms, of more than 25 m depth, had to be realized on the terraces in order to intercept the permeable sandy intercalation and to isolate the MSW from the sandy horizons. Furthermore, the design foresaw the following main works:

1. Base sealing of the landfill by means of a membrane laid on the clayey ground. The last was previously prepared and the sandy levels outcropping on the slopes were sealed with bentonite.

2. Leachate control and collection system with pipeline passing under the downstream retention dam. A double pipeline allows separate gravity conveyance of the leachate coming from both the new and the old landfill sites. The pipe system is accessible for post-mortem controls.
3. Closing system with biogas control network and torch for energy recovery.
4. Groundwater quality control system with independent network for the old landfill.
5. Final capping with vegetal earth; slope greening, seeding of shrubs and grass, planting of high trees; runoff water drainage network.
6. Construction of a service yard, downstream of the landfill, equipped with bureau, toilettes, machine shop, weigh-bridge, wheel-washing, parking.

The design solutions and their modifications in the executive phase are hereinafter described, mainly as regards to the geotechnical aspects of the slope stabilisation.

Figure 1. View of the site: the right slope of the valley with steep scarps is clearly evident.

2 REINFORCED EARTH WALLS

Slope re-shaping was realized by means of reinforced earth wall technology. This solution was characterized by a favorable cost/benefit ratio and by a comparatively low environmental impact. Any different solution would have required significant excavation with higher cost and stronger environmental impact, the technical problems being comparatively complex, as well, due to the geomorphologic conditions of the site.

2.1 *Construction technologies*

The reinforced earth technology groups a number of solutions that have been entering the civil engineering since about 20 years. The reinforced earth system is currently employed for the construction of permanent support works with time duration equal to that of ordinary constructions or to that of structures with high safety level. The structure can be considered like a reinforced gravity construction with geotextiles characterized by opportune properties.

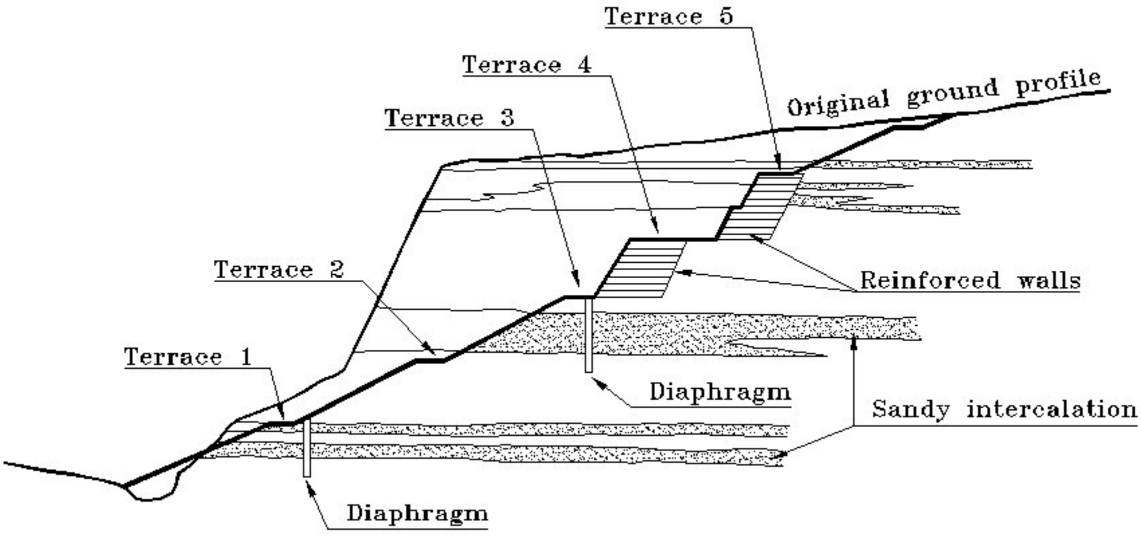

Figure 2. Original ground profile and design cross-section with reinforced walls.

The structure generates sufficient internal strength to support the stress field within a scarp too steep for the material of which it is composed. The mobilization of internal forces mainly occurs:

1. along isolated and discrete alignments (with metal strips);
2. along planes, generally horizontal and parallel (with geogrids and/or geotextiles).

In both cases, two effects are contemporaneously exploited: the resistance of frictional type contrasting the extraction of the metallic strip or of the geo-synthetics from the ground and the effect of pseudo-cohesion deriving from the presence of the reinforcement and from the modification that this involves on the tensional state of the above and underlying grounds.

The adopted solution is based upon the second effect: it aims at giving rise to internal strengths along plains by means of geotextiles; this solution is surer and more reliable in the time.

A nonwoven draw geotextile made up of polyester continuous fiber, with strongly anisotropic strain properties, is inserted in the scarp formations.

The construction of the reinforced earth wall is accomplished according to the following steps (Figure 3):

1. emplacement of non-returnable front metal-caisson;
2. emplacement of reinforcement geotextile along horizontal layers;
3. emplacement of containment geotextile (vegetation-felt);
4. emplacement of filling material, opportunely compacted. In this case, the excavation earth was utilized.

The vegetation-felt, a particular geotextile draw on a polyester pattern, with a 2.5 mm warp, is utilized in order to prevent the scarp erosion and the soil washout; furthermore it forms the bearing layer for the final seeding.

The front metal caisson is employed as an auxiliary emplacement mean, in order to obtain an homogeneous scarp and to allow easy compaction of the filling ground in the front part of the scarp.

Physical models and verification systems of the internal static, which were developed by various Authors (Broms, Murray, Ruegger, Jaecklin, Jewell), are used to determine the length of reinforcement geotextiles.

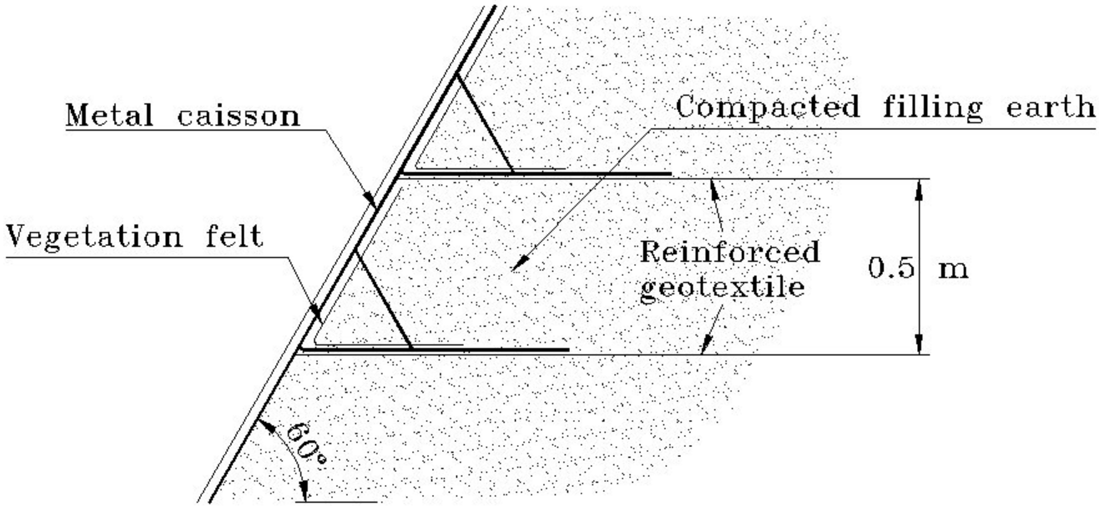

Figure 3. Elements of the reinforced earth wall.

2.2 *Slope regularization: design features*

As previously said, the first priority item in the landfill design and realization was the re-shaping of the slopes and, in particular, that of the northern one showing differences of level of more than 70 meters and sub-vertical scarps, for which the reinforced earth technology was adopted.

The geomorphologic conditions of the northern slope was such to require a preventive consolidation, in order to allow subsequent operations: basin shaping and diaphragming of the sandy horizons. In particular, one of the diaphragms had to be realised halfway of the slope on the terrace at the foot of the reinforced earth structure (Figure 2): its realization would have been impossible without the previous safe arrangement of the uphill slope.

The design solution adopted for the northern slope foresaw the re-shaping according to a terraced profile (five terraces) with two reinforced earth walls: one on the third terrace with a height of 9 m, and one on the fourth terrace with a height of 10 m (Figure 4, 5 and 6). The general characteristics of the walls are the followings:

1. Lower wall - Max height: 9 m. Inclination of the external side: 60°. Length of the top geotextile: 6.0 m. Length of the bottom geotextile: 6.5 m. Wall length: 60 m.
2. Upper wall - Max height: 10.0 m. Intermediate terrace width: 1.0 m. Inclination of the external side: 60°. Length of the top geotextile: 6.0 m. Length of the bottom geotextile: 7.0 m. Wall length: 160 m.

The reinforcement geotextile is a nonwoven draw geotextile made up of polyester continuous fiber, with unit mass of 350 g/m^2. In the longitudinal (laying) direction the geotextile shows up a breaking resistance of 40 kN/m and a strain of 40%, in the transversal direction the resistance is of 20 kN/m and the strain is of 50%.

The limit parameters, under operation, were taken as: resistance of 13 kN/m with strain of 10%. These values were chosen basing upon sample testing carried out by EMPA (Swiss Federal Lab) on the request of the patent owner firm. In site conditions, the confined geotextile shows up higher resistance and rigidity than those of the non-confined one.

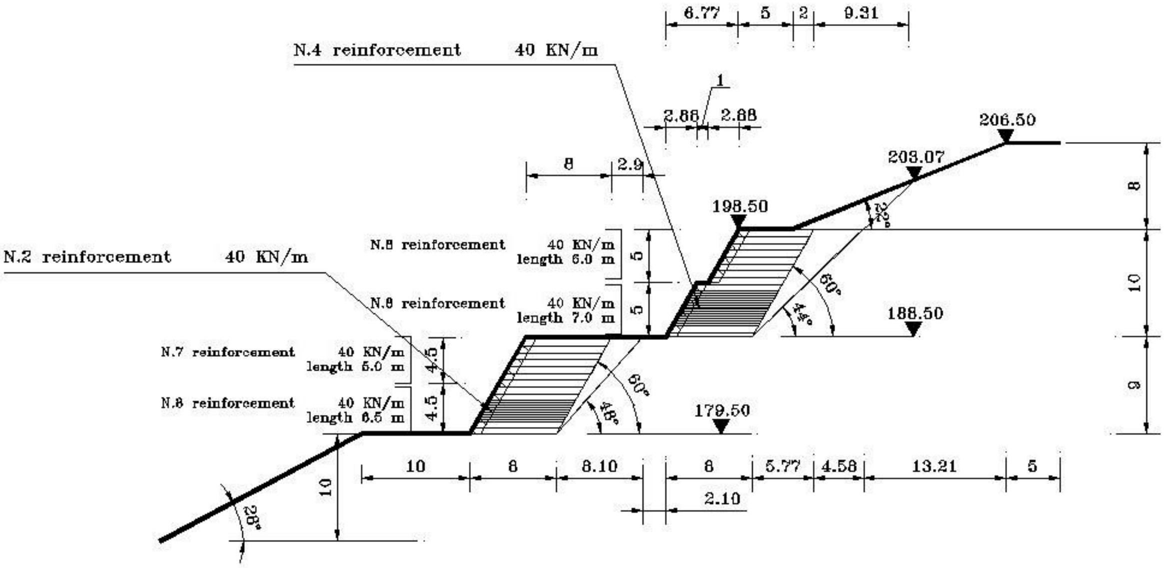

Figure 4. Schematic design of the two walls.

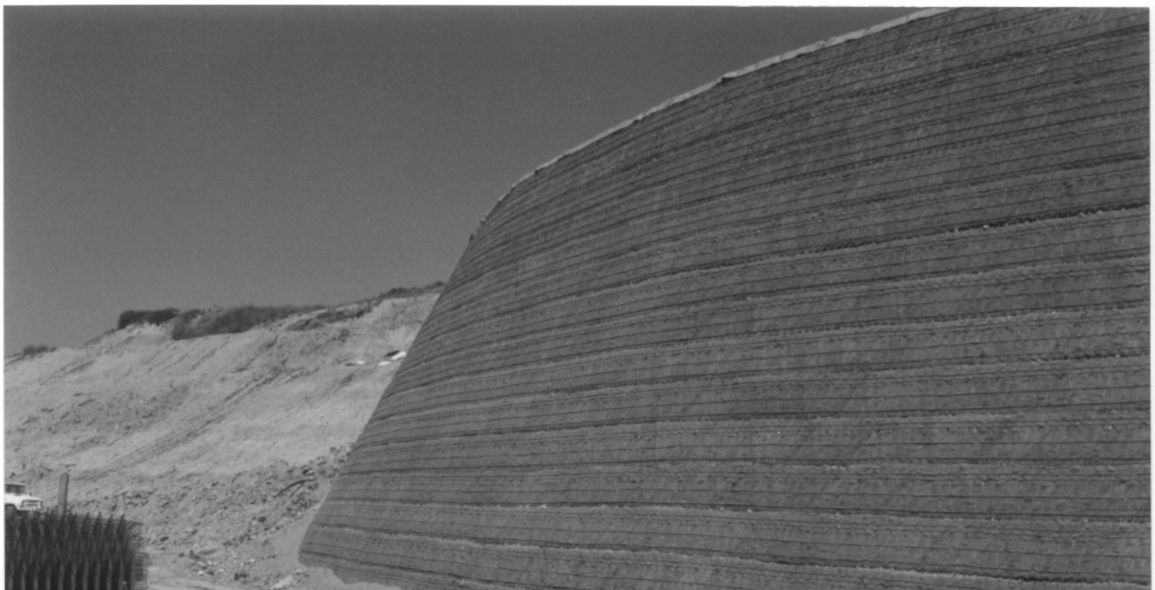

Figure 5. View of the lower wall.

Figure 6. View of the northern slope with the reinforced earth walls. The "kelly" excavator is working at the intermediate diaphragm.

The metal caisson consists of an electric welded net with L-shaped steel rounds having one side laid on the geotextile and the other side facing upward. The function of the metal caisson is that of giving an homogeneous scarp to the external face of the wall and of allowing the easy compaction of the ground up to the scarp front. The metal caisson is not a static element: measurements carried out by the EMPA lab on a 1:10 scaled model showed up a surface pressure of about 1 kN/m^2.

Sub-vertical drains were placed back-wall in order to collect water outflowing of the sandy horizons intercepted by the walls. At this purpose, geotextiles with a unit mass of min 210 g/m^2, bearing at the base micro-screened pipes, were utilized.

The filling terrain resulted from excavation material itself. A mix of sand and sandy gravel with sandy silt was utilized. This material has the following geotechnical properties:

- Angle of friction: 28°-32°
- Cohesion: 0
- Volume mass: 1.8 t/m^3

A prudential value of 28° was taken as angle of friction in the verifications of internal stability. As far as the upstream soil and the structure foundation-plain soil are concerned (mainly over-consolidated clay), the following parameters were taken:

- Angle of friction: 25°
- Cohesion: 2 t/m2
- Volume mass: 1.78 t/m3

The stability of the structures requires the verification of the following conditions:

1. verification of compressibility of the plain of emplacement;
2. verification of creeping;
3. verification of tilting;
4. verification of load-carrying capacity;

5. verification of internal breaking load;
6. verification of external global stability.

The verifications were carried out keeping into account a degree of seismicity of the area S=9. All the above mentioned conditions were verified giving values widely comprised within the limits prescribed by the low.

The analysis of the internal breaking stability was carried out with the method of Ruegger in the version modified by FMPA (University of Stuttgart). This utilizes the classical equilibrium equations of the soil mechanics. Two breaking mechanism were considered: breaking along a steep creeping plain and breaking with a double-body mechanism.

The overall stability of the structure and of slope was analyzed by means of the usual methods of verification of limit equilibrium (methods of Bishop, Janbu etc., in the hypotheses of circular and polygonal surfaces).

The safety factors, resulted from the calculations, are summarized in the tables hereinafter reported.

Table 1. Verification of creeping and tilting

Verification	Fs Static conditions		Fs Dynamic conditions	
	Lower wall	Upper wall	Lower wall	Upper wall
Creeping	5.5	2.79	2.63	1.46
Tilting	22.64	9.97	8.57	4.52

Table 2. Verification of internal breaking stability (I.B.S.)

Verification	Fs_{geo} Steep creeping plain		Fs_{geo} Double body	
	Lower wall	Upper wall	Lower wall	Upper wall
I.B.S.	22.64	9.97	8.57	4.52