OVERALL STABILIZATION OF THE MASSA MARTANA'S RAVINE (ITALY) THROUGH THE USE OF HIGH STRENGTH PVA GEOGRIDS AND OTHER GEOSYNTHETCS FOR THE OPTIMISATION OF THE HYDRAULIC REGIME

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Abstract: The "Fosso della Rocca" is one of the 3 big flumes around the municipality of Massa Martana located in the province of Perugia (Italy). As a result of progressive erosion problems the cliff near the village became subject to a condition of critical stability.

In order to solve these stability problems and reclaim land space around the village it was decided to fill the 38 m high ravine for a length of approx. 160 m, using the rubble from the demolition of local buildings, resulting from the earthquake of 1997, and fill material from neighbouring quarries.

In the final design profile, the stream runs above the new ground level along a canal with trapezoidal section. To limit direct infiltration into the constructed soil mass a specially roughened Geocomposite Clay Liner (GCL) was adopted and the surface of the confining soil layer was protected from erosion with geomats.

The front of the embankment has an amphitheatre shape, in order to support the sides on the cliff shoulders, constructed from seven banks of steep reinforced slopes, each approx. 5 m high. The stream flows down along this front through water chutes and dissipation basins. At the toe of the embankment, a reinforced concrete wall has been constructed to prevent further erosion problems.

As the foundation soil was very soft, overall stability problems of the new embankment were solved using very long length layers of 800 kN/m PVA geogrids. This solution was chosen to avoid the use of large concrete piles, resulting in a more economical and flexible solution.

A drainage system was incorporated into the body of the embankment with several horizontal drainage blankets interconnected with vertical pipes. An appropriate geotextile filter was used to avoid clogging.

Keywords: reinforced earth structure, polyvinyl alcohol, alkalinity, filtration, geocomposite clay liner (GCL), erosion control.

INTRODUCTION

In May 1997 an earthquake caused significant damage to the city of Massa Martana located in the province of Perugia in Italy. The city of Massa Martana is founded on a continental sedimentary plate of inferior Pleistocene rocks which are very stratified and slightly fractured. The erosion caused by the watercourses around the city has created big ravines surrounding the north, west and south sides of the plate, with vertical walls subjected to frequent events of slope failures and rotational landslides. This situation is aggravated as a result of the structural configuration of the soil layers. The earthquake events caused a rapid deterioration of the overall situation putting the existing buildings located close to the cliff edge at risk.

The stabilization and consolidation works of "Fosso della Rocca" ravine, have been carried out through the filling of the 38 m deep gully for a length of approximately 160 m, the stabilization of the vertical walls by means of nailing and the construction of a drainage system in the body of the filling material.

In the final design profile, the stream runs above the new ground level along a canal with trapezoidal section. To limit direct infiltration into the constructed soil mass a special roughened GCL was adopted and the surface of the confining soil layer was protected against erosion with geomats.

Main landslides events and previous works

A dormant landslide (Figure 1) is apparent located along the northern retaining wall that confines Massa Martana's village.

Figure 1. Landslide at the toe of the retaining wall bordering the village

This landslide, occurred for the first time in the '60s, it has been reactivated several times in subsequent phases. The landslide body has been partially eroded at the toe due to the water flow of "Fosso della Rocca" stream and, gabbions filled with stones have been installed to minimise the erosion through critical zones.

Along the same side, towards the throat of the gully, on 29 March 1981 another significant landslide occurred (Figure 2). The collapse of wall, with rotational and translational movements, brought large quantities of debris down into the gully.

Figure 2. Landslide at the head of the ravine (1981)

The soil displaced during the landslide was formed of blocks of travertine sands mixed with sandy loam and gravel. Behind the wall face, a long step of 50-60 cm in height was present, evidence of deeper sliding surfaces.

The observation of the ravine situation revealed large areas in an unstable condition, bounded by fractures and discontinuous stratigraphic surfaces. Moreover, it was possible to detect the progressive regression of the wall due to erosion caused by water and by thermoclastic problems. These were further aggravated by the incoherent nature of the soil.

Field trials and laboratory test

In addition to the trials and tests made in previous years, a further extensive program of trials and laboratory test was carried out in order to obtain a geological and geotechnical characterization of the area of "Fosso della Rocca". Five test holes, up to 25 – 30 m depth, were formed between November 2001 and January 2002. A complete suite of laboratory analysis was undertaken on the recovered samples, in particular, soil classification, soil graduation, liquid limit, plasticity, permeability and peak and residual shear strength in both consolidated, drained condition & undrained consolidated condition. Furthermore, a sequence of tests on site were undertaken including, Standard Penetration Test (STP), in-situ permeability ("Le Franc" method) and in-situ shear strength using the pocket penetrometer. A number of piezometers were installed to monitor the water levels in the soil.

Geology

Clearance of the vegetation on the ravine's slopes allowed access to the slopes for collection of geological and geotechnical data. The geological and hydrogeological instability has was analysed, as well as the structural and lithostratigraphic characteristics of the project area. The seismic characteristics of the area were also evaluated.

In general, the soil layers are a base layer of riverwash (S.Maria di Siciliano), mostly comprising silty sands, laid on un upper formation (Acquasparta), composed of a sequence of clay layers alternating with silty sands and medium to course sands, with deposit of carbonate and, layers of lithoid limestone.

From a seismic point of view, Massa Martana's Village has been divided in micro zones and, for this reason, the standard acceleration a/g established for that region must be incremented with different factors of seismic amplification. In this particular case, at the top the of the ravine, an amplification factor equal to 2 has been applied while at the toe (bed of Fosso della Rocca stream) the amplification factor was of 1.5.

GEOTECHNICAL SOLUTION

General description of the project.

The overall situation of marginal stability, aggravated by the progressive erosion of the ravine slopes, represented a danger to the buildings in the village, in particular, the historical town.

The aim of the project was to eliminate the existing stability problems and at the same time, recover part of the ground lost around the city as the result of the historical landslides. To achieve this it was decided to fill the "V" shaped stream gully, for a total length of approximately 160 m. At its greatest dimensions the gully was approximately 90 m wide, with a depth of nearly 38 m. The total volume of filling material used was in the order of 180 000 m^2.

The filling material was a mix of masonry debris (maximum size 100 mm) resulting from the demolished buildings of Massa Martana after the earthquake of 1997 and fill material from local quarries.

This solution presented several technical problems, which have been solved adopting different types of geosynthetics with a range of functions, as described below:

- Reinforcement: stabilization of the front and the base of the embankment with PVA geogrids;

- Filtration: geotextile filter used in the drainage system incorporated into the embankment body;
- Lining: waterproofing of Fosso della Rocca stream with geocomposite clay liner (GCL);
- Erosion control: geomats used to protect wet and dry slopes.

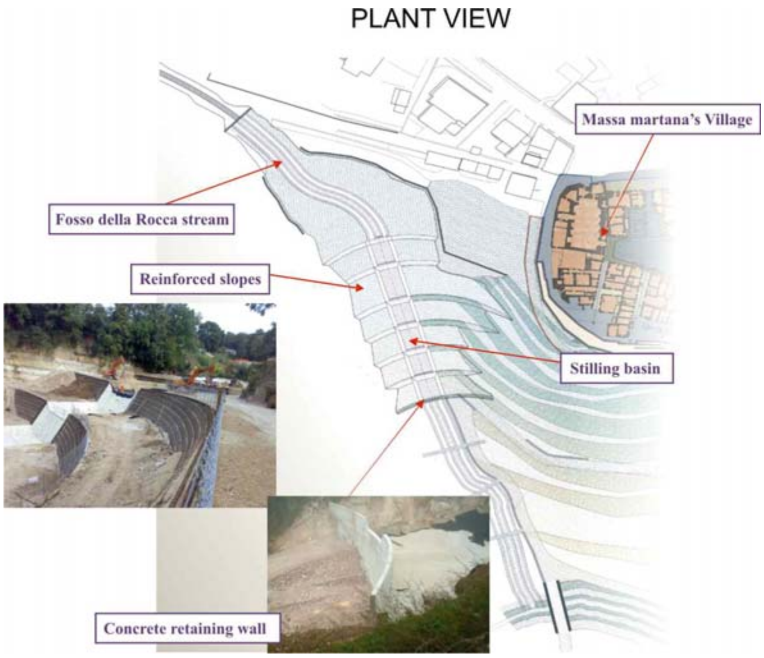

Figure 3. Plant view of the project

Reinforcement: stabilization of the front and the base of the embankment with PVA geogrids

The front of the embankment has been stabilized by 8 banks of steep reinforced slopes, 7 of 5 m and one of 3 m in height, with a total height of 38 m high, spaced by earth berms. The face configuration was designed to accommodate the hydraulic design of the central water chute. The stream runs over the embankment for about 70 m and then falls down a sequence of 6 water slides, each of 5 m in height and 6 stilling basins with lengths varying between 10.5 m a 15.9 m. At the base of the embankment the subgrade has been treated with a layer of compacted crushed stone.

Due to the use of demolition rubble for the partial filling of the embankment, a high degree of alkalinity was expected ($9<pH<12$). For this reason geogrids made with polyvinyl alcohol (PVA) yarns were specified. In addition to the high chemical resistance, PVA geogrids are characterized for their high modulus in the short and long term, which gives very low elongation at failure ($\varepsilon \leq 6\%$) and low creep distortion.

The front of the banks were inclined at 60° to the horizontal except at the location of the water chute where they were shaped to the trapezoidal section of the channel. Steel meshes of 15 x 15 cm made with bars of 8mm diameter were used as a sacrificial shuttering in order to keep a regular face to the slopes. Furthermore a synthetic geonet was placed inside the front of every layer in order to minimise erosion problems. The geotechnical parameters for the soils that were assumed for static calculation are shown in Table 1, with the deepest at the top:

Table 1. Summary of assumed geotechnical parameters

Soil description	Thickness [m]	ϕ [°]	C [kN/m^2]	γ [kN/m^3]
Sandy silt	Lowest layer	26	0	20
Silty sand	2.7	30	0	20
Clay and silt	2.8	25	50	20
Sandy silt	6.6	26	0	20
Silty sand	6.4	30	0	20
Reclaimed land	4.0	35	0	20
Drainage layer (gravel)	-	35	0	20
Filling of embankment	-	27	0	20
Filling of reinforced soil	-	35	0	20

The ground water level was taken as 2 m below ground level. Due to the poor geotechnical characteristics of the soil and taking into account the seismic acceleration ($a/g = 0.14$), the reinforcement of just the face of the embankment was insufficient to stabilize it because deep sliding surfaces gave rise to issues of overall stability. The first approach was to adopt reinforced concrete piles of large diameter (1200 mm approximate diameter), placed at the toe of the embankment in order to increase the shear resistance intercepting the deep sliding surfaces. This solution presented two problems: firstly the high cost, and second, it would be a rigid structure placed at the toe of a highly flexible embankment, and would not be able to follow the settlements and deformations of the reinforced soils behind. The chosen solution was to increase the shear resistance of the soil intercepting the critical sliding surfaces with long geogrids placed horizontally at the base of the embankment. The use of this base reinforcement, saved a significant amount of construction time.

During the design, calculations of internal, compound, sliding and overall stability of the whole reinforced embankment and of every individual reinforced unit were performed using circular sliding surfaces (Bishop) and polygonal ones (Janbu). The minimum required factors of safety have been fixed in the following way:

a) FS ≥ 1.3 under seismic condition with the typical horizontal acceleration a/g = 0.07 for that region;

b) a factor FS ≥ 1.1 has been accepted under seismic condition when applied the amplification factor of 2 (a/g = 0.14).

In addition, calculations in static condition were undertaken. After calculation, the required design strength and the anchor length of every geogrid have were established, these are illustrated in Figure 3.

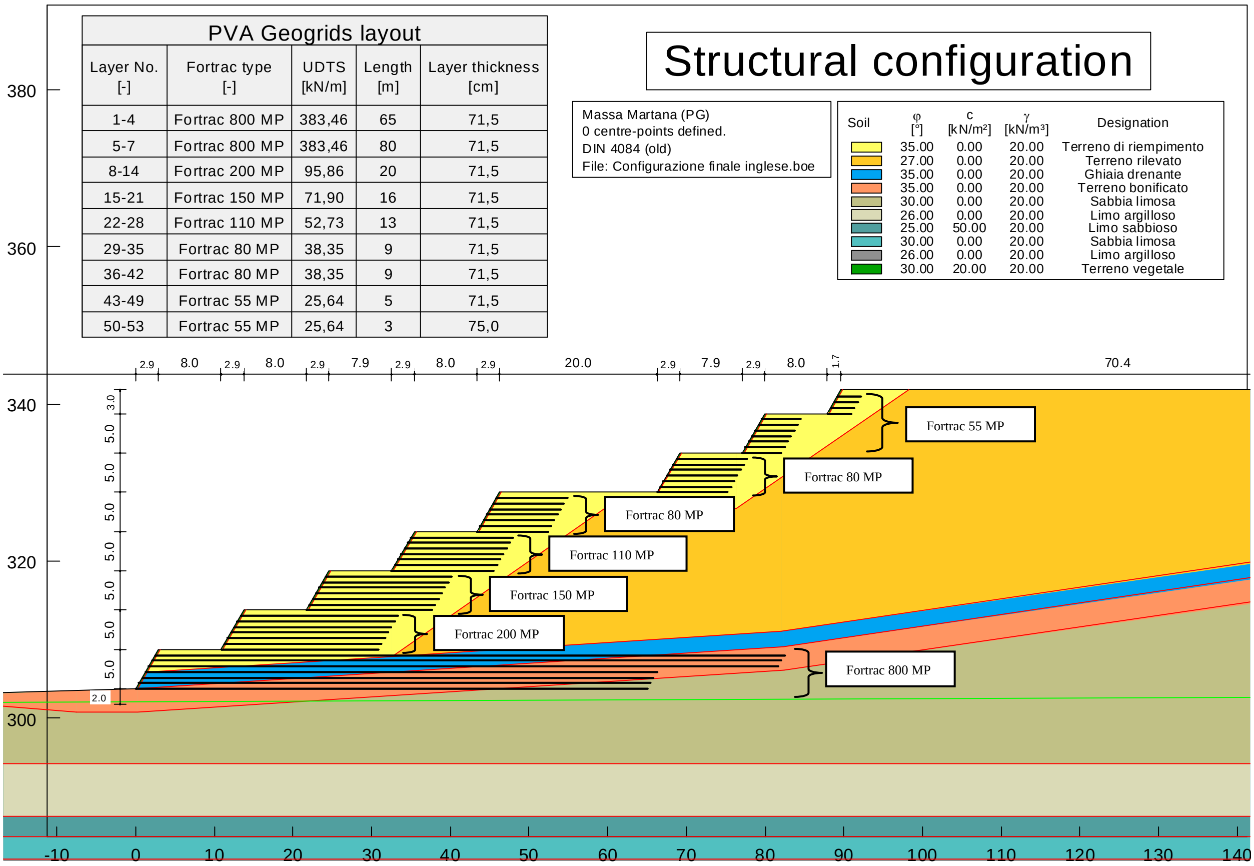

Figure 4. Structural configuration of most critical section in the reinforced embankment

The first bank was reinforced with PVA geogrids of 800 kN/m with lengths ranging between 65 m and 80 m to intercept very deep sliding surfaces. The upper banks have been reinforced successively with PVA geogrids of 200 kN/m, 150 kN/m, 110 KN/m, 80 kN/m, 55 kN/m. The design tensile strength of every geogrid has been calculated according with the British Standard BS 8006, and any reduction factor applied (due to creep, mechanical damage, environmental attack) has been supported by specific certificates and test reports. The spacing between geogrids was 72 cm and compaction was undertaken in 24 cm layers, to reach 95% of the modified ASSHO density.

Furthermore, the deformation of the whole system has been analysed using a Finite Element Modeling (F.E.M.) software package, (FLAC). According to this numerical model, settlements of 30 cm at the central part of the embankment and settlements of 10 cm along the contact line with the lateral walls of the ravine are expected. A monitoring program has been undertaken to measure the in-situ deformations of the system.

At the front of first bank, a concrete retaining wall was built to protect the toe of the embankment from erosion. Moreover, an erosion simulation of the toe has been made lowering the bed of “Fosso della Rocca” downstream from 1 to 10 m. This scenario resulted in the requirement for some additional reinforcement using layers of 200 kN/m PVA geogrids located in the middle of the embankment with a precise layout. Further simulations have been carried out decreasing the geotechnical parameters of cohesive soils. The front of the embankment has an amphitheatre shape, in order to support the sides on the cliff shoulders.

Safety at work

As almost all of the works were undertaken under the steep walls of the ravine, it was necessary to secure the walls against sliding and falling blocks during the work operations. To achieve this the existing vegetation on the walls was cut off and unstable blocks of soil were removed. A steel mesh was placed, covering the walls, which was fixed at the top by the means of a perimetric beam founded on micro piles 9 m long reinforced with Dywidag bars and spaced 1.5 m. By the competition of the works a large number of the steel meshes were buried.

Filtration: geotextile filter used in the drainage system incorporated into the embankment body

A drainage system to collect and discharge the water coming from springs, from infiltrated rain water and from potential leakage of water coming from the stream was installed within the embankment. The drainage system comprises a sequence of horizontal blankets of gravel (grain size 50-100 mm) interconnected with vertical perforated drainage pipes filled with gravel. Both, mattresses and pipes have been filtered using a geotextile woven filter to avoid the progressive clogging of the gravel. Figure 5 shows the layout of the internal drainage grid.

Figure 5. Vertical pipes interconnecting horizontal drainage blankets, both covered with a woven filter

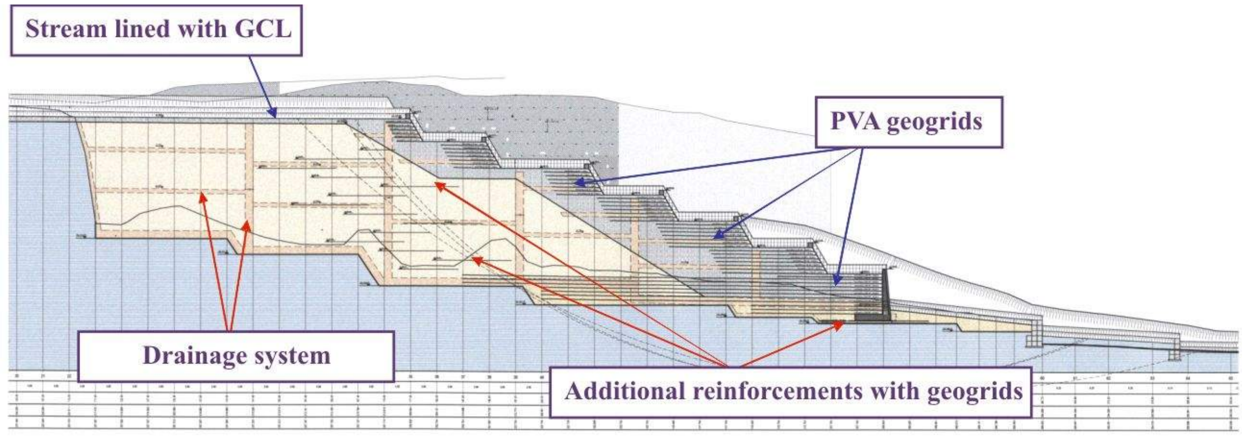

Figure 6. Main section

A woven filter was specified rather than a non woven geotextile because of its high permeability and reduced tendency to clogging, as well as its high resistance to mechanical damage during installation. The technical characteristics of the woven filter are shown in Table 2.

Table 2. Main technical characteristics of the filter woven HaTe® C50.002

Characteristic	Unit		Standard
Raw material	-	PE/PP	-
Ultimate tensile strength (long/transv)	kN/m	≥ 45/55	ISO 10.319
Strain at nominal strength (long/transv)	%	≤ 27/23	ISO 10.319
Water permeability	m/s	100×10^{-3}	EN ISO 11.058
Pore diameter	μm	200	EN ISO 12.956

Lining: waterproofing of Fosso della Rocca stream with geocomposite clay liner (GCL)

The "Fosso della Rocca" stream has been engineered with a channel of trapezoidal section and flows on the embankment with a slope of 0,5% for about 70 m, then flows through a sequence of 6 water chutes, each 5 meters in height and stilling basins of 10.5 to 15.9 meters in length, built alternatively on the steep reinforced slopes and on the berms. The downstream water course is reached after crossing two weirs with stilling basins. The section of the stream that flows over the embankment is represented in Figure 7.

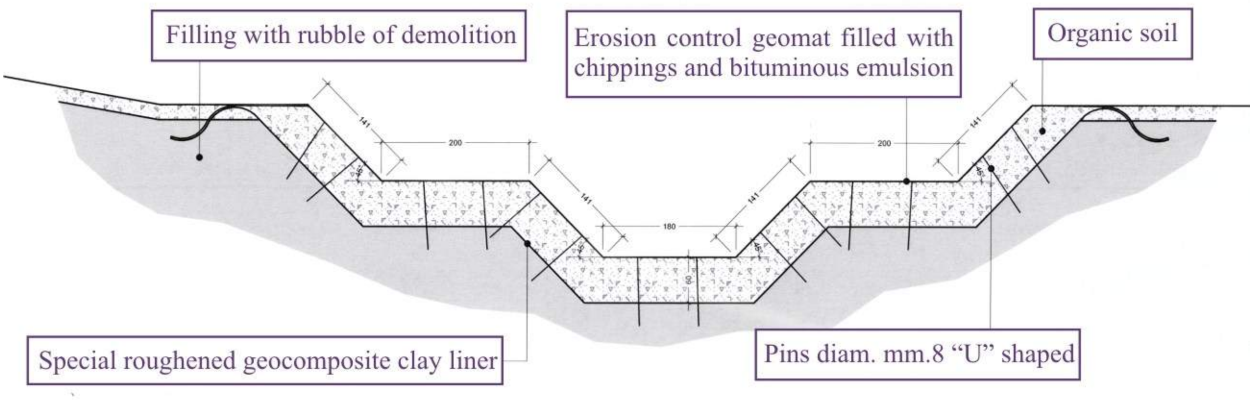

Figure 7. Cross section of the stream

The stream was lined with a GCL to limit direct infiltration of water into the constructed soil mass. The GCL has been confined with 60 cm of soil and, to avoid possible sliding along the channel a special type of GCL with rough surfaces in order to increment the friction with the cover soil was used.

The technical characteristics of the Geocomposite clay liner are shown in Table 3.

Table 3. Main technical characteristics of the GCL NaBento® RL-N

Characteristic	Unit		Standard
Supporting layers	-	PP fabrics roughened with chippings	-
Unit weight of sodium bentonite	gr/m^2	4,500	EN ISO 9864
Total weight	gr/m^2	5,500	EN ISO 9864
Thickness in dry condition	mm	7	EN ISO 9863-2
Ultimate tensile strength (long/transv)	kN/m	≥ 20/30	ISO 10.319
Strain at nominal strength (long/transv)	%	≤ 25/25	ISO 10.319
Internal shear strength	°	> 35	-
Water permeability Kv (i=30, σ=30kPa)	m/s	$\leq 5 \times 10^{-11}$	DIN 18130 T1

Figure 8. Section of "Fosso della Rocca" stream in the stilling basin. GCL installation

Erosion control: geomats used to protect wet and dry slopes

The revetment of the channel has been divided in two typologies:

a) the revetment of the horizontal stretch,

b) the revetment of the water chute and spilling basins.

The revetment of the horizontal stretch of the channel, at the top of the embankment and downstream, has been made using three dimensional PP geomats filled with stone chippings on which a basic bituminous emulsion has been sprayed. This kind of revetment allows vegetation growth and, at the same time, gives an efficient protection against erosion for water velocities up to 3 m/s when the vegetation is well developed. Also, three dimensional mats filled with organic soil have been installed on the peripheral dry slopes linked with the lateral walls of the ravine (see Figure 7).

On the face of all steep reinforced slopes and on all surfaces protected with geomats, an intensive hydroseed with mulch have been specified.

Figure 9. Overall view. Reinforced slopes, central water chute and erosion control geomats on the peripheral slopes

CONCLUSION

The overall stabilization of Massa Martana's ravine through the filling with soil, gave rise to a number of issues that were overcome using geosynthetics in a number of different functions:

- Soil reinforcement for the stabilization of the front and the base of the embankment, by means of high strength PVA geogrids;
- Constuction of a flexible and cost effective foundation, eliminating the need for a rigid and expensive solution with large concrete piles, through the use of long high strength geogrids (800 kN/m);
- Reinforcement of soils with high level of alkalinity trough the use of PVA geogrids;
- Filtration of drainage layers and pipes to avoid clogging, through the use of a woven geotextile filter;
- Lining the trapezoidal section of the stream to avoid infiltration into the constructed soil mass, through the use of a special roughened geocomposite clay liner (GCL);
- Erosion control of wet and dry slopes through the use of synthetic geomats.

In addition, the use of geosynthetics in this project allowed the construction of flexible structures with optimal behaviour in seismic areas.

Figure 10. Overall view of the work and Massa Martana village.

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REFERENCES

Bishop, A.W. 1955. The use of the slip circle in the stability analysis of slopes, *Geotechnique, 5, No. 1,7-17*.

British Standard - BS 8006 : 1995. Code of practice for Strengthened/reinforced soils and other fills.

TRI . 2002. Report: Creep and creep-rupture behaviour of Fortrac® M (PVA) geogrids.

TRI. 2000. Report: Installation damage testing of Huesker geosynthetics