Design *and* Practice *of* Geosynthetic-Reinforced Soil Structures

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Segmental Retaining Walls and Steep Slopes Reinforced with PVA Geogrids in the Energy Polo of Massa Martana

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ABSTRACT

This work concerns the construction of segmental retaining walls and steep slopes reinforced with PVA geogrids in the Energy Polo for the Production of Renewable Energy, located in Massa Martana (PG), Italy.

The industrial area is rectangular and is located along a hillside, therefore was necessary the construction of retaining walls at the upstream of the mountainside, along the lateral sides and at the downstream side of the whole area, in order to obtain a wide horizontal surfaces. For this purpose 3,700 sqm of Segmental Retaining Walls (SRW) reinforced with geogrids up to 11.6 m high were constructed, while in an outskirts area was built about 1500 sqm of a Steep Reinforced Slope (SRS), up to 12 m high, with vegetated facing.

This method of construction has been decisive for the choice of this type of solution, because the execution of the walls started simultaneously with the construction of the total energy plant, then the system chosen must minimize interferences with other multiple processes and allow a reduction of working time. Furthermore, due to the high visibility of this project, also the environmental integration has been considered, therefore the aesthetic aspects were carefully evaluated.

As a filling material for the walls it was possible to reuse the clayey soil present in site, after suitable lime stabilization, thanks to the adoption of geogrids made with polyvinylalcohol (PVA) characterized by high chemical resistance in alkaline environments (pH> 12,5). At the back of the walls drainage geocomposites have been provided.

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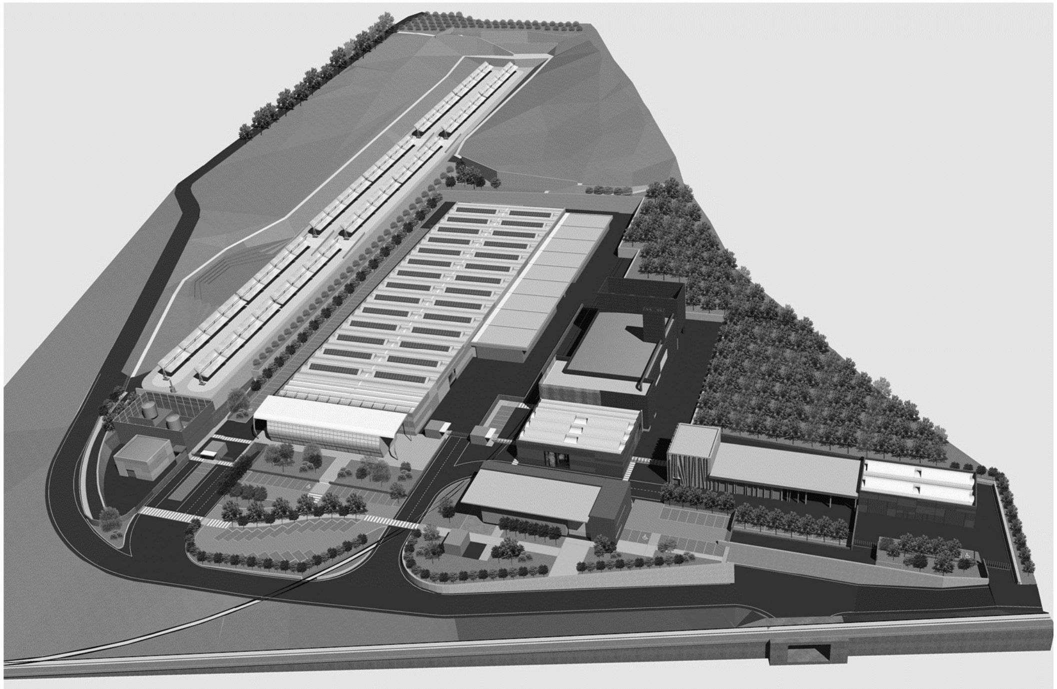

Figure 1. Virtual 3D view of the Energy Polo plant.

INTRODUCTION

The Energy Polo for the Production of Renewable Energy, is located in Massa Martana, a small town in the province of Perugia (Italy), connected to the highway E 45 and Central Umbra Railway.

The work, which covers an area of 85,269 m^2, was carried out in an abandoned industrial area, which was once home to a brick kiln.

The project of the Energy Polo, foresaw the creation of an Experimental Solar Centre, a Cogeneration Plant fuelled with wooden-cellulosic biomass, a plant for production of solar receiver tubes, a plant for production of biofuels, with respective buildings and conference centre (Figure 1).

Besides the execution of the main buildings of the Energy District have been also constructed all the infrastructure such as internal roads, car parking areas, technological networks (water, sewer, electrical conduits, cable ducts telephone, gas networks, fire fighting networks, public lighting), retaining walls, green works and fences.

Due to the fact that the shape of site is nearly rectangular and is positioned along a hillside, it was necessary to construct retaining walls at the upstream of the mountainside, along the lateral sides, and at the downstream side of the total area, in order to obtain wide horizontal surfaces.

Urbanization works included the excavation of 230,000 cubic meters of clayed soil and provision of 52,518 cubic meters of lime stabilized backfill for retaining walls. Around the industrial buildings, Segmental Retaining Walls (SRW) reinforced with geogrids were constructed, while in an outskirt area was also made a Steep Reinforced Slope (SRS) with green facing.

The SRW has an inclination of about 83° from horizontal and variable heights from 2 to 11.6 m approximately, with a total surface of about 3,700 m^2. For calculation purposes have been identified 5 typical sections. The SRS has almost a constant height of about 12 meters and its front has a slope of 60° from the horizontal, with a total surface of about 1,500 m^2. Both walls are reinforced with PVA geogrids and, in some sections, are separated by intermediate berms. At the back of the walls drainage geocomposites have been provided.

DESIGN REQUIREMENTS

Many aspects had to be taken into account to find the solution that fulfils different technical, practical and aesthetical requirements. As reported above, the area used to be place of a brick kiln, therefore the soil in site is naturally composed mainly of clay. Furthermore, several underground water streams have been detected. From a seismicity point of view, this area is classified as a high active one.
Interferences between the construction of the wall and other simultaneous building works should be minimized as much as possible. Therefore these works required perfect coordination and had to be done in max. 6 months.

The retaining walls reinforced with geogrids presented technical and aesthetic advantages:

1. Both, SRW and SRS, have similar operating mode of construction, as, from a structural point of view, it can be agreed that the SRW are a particular case of SRS with block facing. Therefore the same skilled workers had been employed for the construction of both walls.
2. The installation of the system is simple, fast and the number of workers for its execution is limited.
3. Unlike traditional concrete retaining walls, SRW and SRS can be loaded while they are built, because they don't require a waiting time for concrete curing before subjecting them to the earth pressure. Thus, the fill soil could be lime stabilized and used during construction.
4. Ductility and energy dissipation capacity of RSWs and SRSs, made the systems suitable to be adopted in an area of high seismic activity such as Massa Martana.
5. Clay soil present in site could be reused as filling material for the walls, after adequate lime stabilization, thanks to the use of geogrids made with polyvinylalcohol (PVA) characterized by high modulus, low creep and chemical resistance in highly basic environments (pH> 12,5).
6. Reliability and performance of RSW system were supported by the experience in similar relevant works in the world and by appropriate certifications of adopted materials, which allow to verify the behaviour over time of both, geogrids as a reinforcement and concrete blocks as facing.
7. The external splitted finishing of the blocks ensured a high aesthetic value. Furthermore, beige coloured customized blocks have been produced to ensure an optimal insertion into the surrounding landscape.
8. The splitted block facing allowed also to drop down maintenance costs with economic benefits in medium / long term.

Figure 2. Lime stabilized soil.

DESIGN DATA

Soil Characteristics

Since the site was a former brick kiln, the soils present in the area are mainly clayey. To create the room for the industrial area was necessary to excavate 230,000 m^3 approximately, thus the earthworks involved large amount of soil to carry to landfills. In order to optimize earthworks it was decided to employ the existing clay as a filling soil of the reinforced walls. Moreover, it had to be considered that a total replacement with granular soils was extremely expensive and time consuming.

For filling purposes the local cohesive soil was previously stabilized with lime, in order to enhance its geotechnical properties (Figure 2).
The lime stabilization technique, usually applied to soils with a high content of clay, consists in mixing the natural soil with calcium oxide (CaO) and the compaction of the mixture at an optimum water content (lime stabilized soil). Due to the chemical properties of calcium oxide, stabilized soil has alkaline properties with a pH value bigger than 12.

Thanks to the lime stabilization, an improvement of shear resistance of the soil is reached. The adopted design values for the calculation of the retaining walls are shown in TABLE I. In the calculation phase these values have been reduced with apposite factors of safety according with Italian Standard NTC 2008 [1].

TABLE I. SUMMARY OF ADOPTED SOIL PARAMETERS.

Soil description	**ϕ' (°)**	**c' [kN/m^2]**	**γ [kN/m^3]**
Filling soil	25	20	20.0
Back soil	23	0	17.0
Foundation soil	23	50	20.0

TABLE II. GEOGRID CHARACTERISTICS.

Material	Fortrac® 80 MP	Fortrac® 55 MP	Fortrac® 35 MP
Description	Polyvinylalcohol (PVA) woven geogrid with polymeric coating		
Ultimate tensile strength (longitudinal)	80 kN/m	55 kN/m	35 kN/m
Elongation	≤ 6 %	≤ 6 %	≤ 6 %
F_{creep}: creep reduction factor (120 yrs)	0,655	0,655	0,655
f_{m11}: reduction factor for consistency of manufacture and availability of data	1,00	1,00	1,00
f_{m12}: reduction factor for extrapolation and manufacture (120 yrs)	1,00	1,00	1,00
f_{m21}: reduction factor for mechanical damage (gravel and sand)	1,08	1,08	1,11
f_{m22}: reduction factor for environmental effects (pH ≥ 9)	1,06	1,06	1,06
LTDS: Long Term Design Strength (120 yrs)	**45,77 kN/m**	**31,47 kN/m**	**19,48 kN/m**

Geogrids

The height of the staggered retaining walls varied from 2,00 m to 11,60 m, thus the stability of the wall has been verified considering 5 typical sections in order to optimize the total cost of the work. The structural configuration of the segmental retaining walls has also been subjected to an optimization by changing the strength and the anchor length of geogrids with the wall height. In the upper part of the walls, due to the lower levels of stresses, PVA geogrids with Ultimate Tensile Strength (UTS) of 35 kN/m have been used, while in the intermediate sector geogrids with UTS of 55 kN/m and in the lowest part geogrids with UTS of 80 kN/m.

In this project the choice of PVA as raw material for reinforcing geogrids has absolutely been mandatory due to chemical issues. Polyvinyl alcohol is a polymer which guarantees very high chemical resistance in alkaline environments, such as lime stabilized soils (pH > 12). Furthermore, these geogrids are characterized for high Young modulus, low creep and very low deformations; features that are relevant for high and almost vertical retaining walls.

Technical characteristics of reinforcing PVA geogrids are shown in TABLE II. The Long Term Design Strength (LTDS) for every material has been calculated according to the BS 8006 using the following equation [2]:

$$LTDS = (F_{creep} \cdot P_{ult}) / (f_{m11} \cdot f_{m12} \cdot f_{m21} \cdot f_{m22}) \quad (1)$$

All the reduction factors have been supported by certified laboratory tests because
the reliability of these values have a fundamental importance in design as they directly affect the overall safety factor of the structure [3].

ISOCHRONUS CURVES

With the isochronous curves, it is possible to obtain the variation of strain with time at different levels of stress applied to the geosynthetics, expressed as a percentage of the Ultimate Tensile Strength (UTS). In Figure 3 the curves related to the PVA geogrids are shown. From this chart it is for example possible to see how

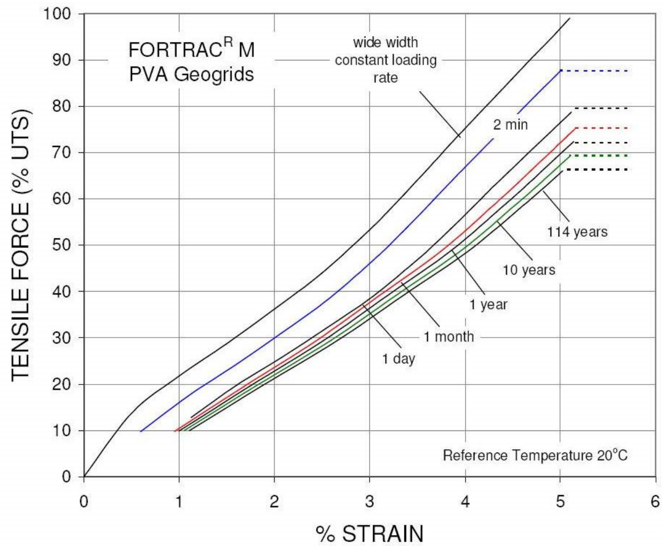

Figure 3. Isochronous stress-strain curves for the Fortrac® M PVA Product Line.

at 55 % of the UTS (more or less the LTDS of the geogrids) the difference between the immediate strain (3,1 %) and the strain at 114 years (4,3 %) is 1,2%, that is, very low. Thus, it is possible to corroborate that deformation of these walls reinforced with these specific types of geogrid will be negligible [4].

Facings

The front of SRWs has an inclination of 83° and, as facing, have been adopted Rockwood vibro-compressed concrete blocks in which the external texture is splitted in three sides in order to create an irregular surface similar to stones. For an optimal environmental integration a customized beige colour for blocks was developed, so, during the production a modified dosage of pigment had been added in the concrete mix

Regarding SRS, the face has an inclination of 60° and was constructed with the help of lost shuttering frameworks made with steel meshes. A layer 30 cm thick of vegetable soil, protected with an erosion control net, was placed at the front of the slope to facilitate growth of vegetation. Finally, a hydroseed was sprayed on the front.

STABILITY ISSUES

Global stability of walls has been verified with simplified method of Bishop [5], assuming circular potential failure surfaces. The safety factor is therefore defined as the ratio of the available shear strength (τ_f) to the shear strength (τ_m) which must be mobilized to maintain a condition of limit equilibrium.

Internal and compound stability of the Segmental Retaining Walls have been performed analyzing both circular (Bishop) and polygonal (Modified Janbu) failure surfaces.

A special care has been taken into account when dealing with the connection between PVA geogrids and blocks because a failure of this connection, could cause a partial collapse of the structure. Due to this reason it had been possible to use a

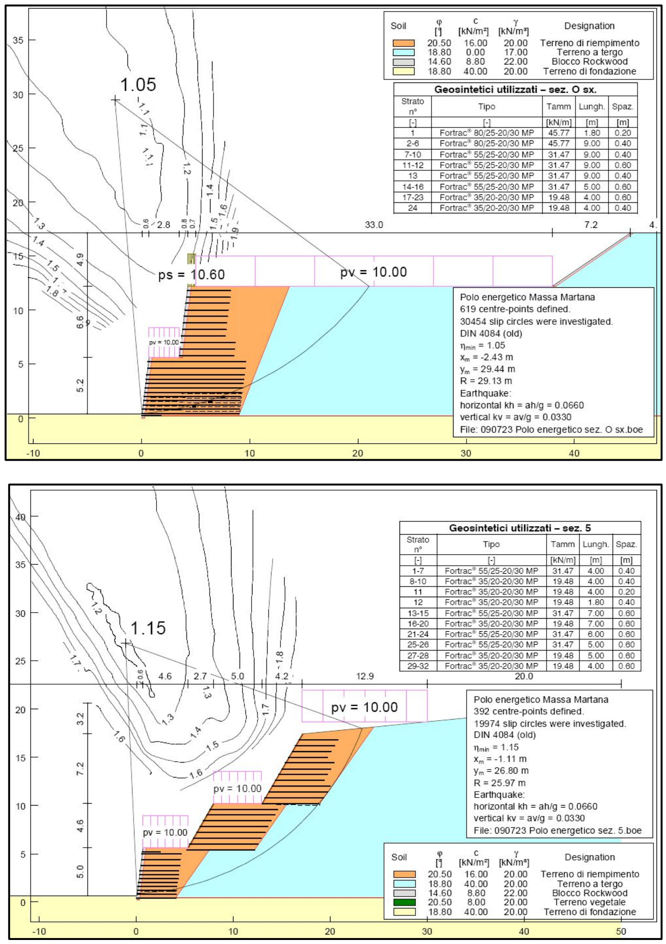

Figure 4. Critical sections of SRW and SRS.

combination of PVA geogrids and concrete blocks which had already been subjected to extensive testing programme in terms of pull-out and shear resistance of the connection [6]. The connection stability has been verified for every single interface between geogrid and block, following the procedure fixed by the American Federal Highway Administration [7].

The vertical spacing between geogrids has been varied from a minimum of 0.20 m to a maximum of 0.60 m throughout the height of the walls.

In Figure 4, two critical cross section used for the analysis are shown. The different types of geogrids used are summarized in the table, and the geotechnical characteristics of soils considered for the analysis are indicated.

The seismic effect, with a horizontal acceleration of 0.066 g and vertical acceleration of 0.033 g, has been taken into account in all performed calculations.

The long term design strength (LTDS) of the geogrids has been taken into account in the determination of final safety factors, which have to be bigger than 1.0 for internal and compound stability and bigger that 1.1 for global stability, as required by the current Italian standards.

Water pore pressure has not been taken into account in the calculation. With this regards, drainage geocomposites have been installed at the back of SRWs and SRSs to intercept any potential water arrivals from underground streams present in that area.

Figure 5. View of SRW during construction.

Figure 6. View of SRS during construction.

EXECUTION OF THE WORKS

Construction of geogrid reinforced retaining walls is quite simple and fast. The system is very versatile and allows to follow any kind of shape in easy way without using frameworks (Figures 5,6 and 7). The construction of the walls was completed in different phases between July and December 2010.

The noteworthy issues concerning the execution of the SRW in the Energy Polo are the following:

1. casting of an unreinforced poor concrete levelling pad, 15 cm thick and 100 cm wide directly on the compacted foundation soil, with a perfectly horizontal surface to insure full contact to the base surface of the first course of blocks.
2. Installation of about 0,5 m^3 of gravel per square meter of front of SRW as a filling a drainage layer.

3. Installation of drainage geocomposites at the back of SRW and SRS.
4. quick execution of the works: An average of 30 square meters of finished facing per working day had been executed by a team of six workers; with the help of one roller, one excavator and one bulldozer.

Figure 7. Variations of height and shape shown the versatility of the system.

CONCLUSION

The choice of SRW and SRS as retaining walls proved to be a valid solution from technical and aesthetic points of view: a) excellent behaviour against earthquakes, b) easy and fast construction, c) versatility to follow any shape and topographic irregularities, d) environmental friendly, e) production of blocks with customized colour.

Thanks to good chemical resistance in alkaline environments of PVA geogrids (pH > 12) it was possible to use, as filling material for SRW and SRS, the clayey soil present in site through a suitable lime stabilization.

The geogrid reinforced retaining walls technique allowed to optimize the execution time. The construction of the walls has been done simultaneously without interfering with earthworks and the construction of other buildings. Furthermore, with these systems, there's no need to wait for the curing of the concrete before laying the backfill and putting under load, as happens with traditional concrete walls.

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