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The first mining-landfill capping in Italy

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ABSTRACT: The Rigoloccio mine in Tuscany was closed after more than 70 years of activity. The entire area has been reclaimed. The site morphology has been modelled, a capping system has been designed and a proper "green reclamation" has been developed. During construction a failure occurred on a limited portion (3%) of the slopes and it was the case of making a full set of analyses to understand the problem. The final results achieved are excellent and the solution has been used to new ongoing sites.

1 INTRODUCTION

The Rigoloccio mine, located in Gavorrano (GR) in Tuscany, was opened at the beginning of 20th century to extract pyrites and was closed – after more than 70 years of activity – at the beginning of 80's. From the beginning of the mining activity all inert materials coming from the mine tunnel excavations have been stored in the area of Rigoloccio. This determined the actual existing profile; the visual impact is very low due to the fact that the landscape is hilly and there were no evident trays of this storage

Following the end of the activities a full range of tests and analyses have been carried out on the stocked material and leachate and – in spite not negative results on the quality of the soil and leachate – it has been decided to reclaim the area with a full security system.

The competent authorities (ARPAT and "The Mining Corp") established that possibly in the area could also have been stored other mineral components since present in the excavation wastes. Therefore the all area had to be considered as a source of potentially dangerous environmental pollution source and had to be secured.

2 DESIGN SOLUTION

2.1 *Scope*

The design solution aim was the site reclamation and the greenery rehabilitation according to the surrounding landscape. The project has been developed according to the following phases:

- Site morphological modelling;
- Waterproofing of the entire area;
- Meteoric rainfalls draining system;
- Greenery rehabilitation.

2.2 *Morphological modelling*

The Northwest site and the central body of the landfill have been modelled filling and cancelling out the creeks caused by the rainfall. These creeks were the main cause of the valley landscape degrades along the direction of the ditch.

The excavation has been done in order to achieve a slope inclination of 30 degrees. A berm has been placed at a quote of 120 m in the main body of the landfill; the berm width was at least 4.0 m in order to enable the safety passage of tired motor hard vehicles.

The excavation exceeding material has been placed and compacted on the flat area on the top of the main portion of the landfill. The filling height was about (has not been over) 1.0 m; the area has been modelled to have a light inclination in the valley direction.

Figure 1. Reno Mattresses lining and bridles built at the toe of the slope of the capping.

2.3 *Hydraulic Management*

The Rogoloccio channel laps the landfill. The landfill name itself comes from the channel presence. The riverbed is characterised by a steep inclination and by the presence of sand. Difficulties were often caused by the presence of mud in the nearby properties and in the public roads.

The aim was to train the river to avoid further erosion problems and to limit the possibility of new overflowing. These happenings could cause erosion problems and infiltration events to the landfill itself.

To solve these problems the torrent bed was lined with Reno Mattresses and six bridles done with double twist steel mesh gabions were build in the steepest and most erosive portion of the torrent (Figure 1).

Two lamination tanks were also build at the top and bottom of the landfill area to decrease as much as possible the erosion capability of the torrent nearby the landfill area.

2.4 *Capping*

2.4.1 *The original capping solution*

The solution developed was different for the flat and slopping surfaces.

The flat area is the landfill central portion: on it a 40 cm layer of clay material was laid. Above this clay material it was laid a high density polyethylene smooth membrane having a thickness of 2.0 mm. On top it was laid a drainage layer for meteoric rainfalls having a thickness of 15 cm and a granulometry range from o to 5. The sealing package was finished by a 50 cm layer of vegetative soil.

The original design solution for the slopes detailed the use of a textured high density polyethylene membrane and the use of a drainage composite (a high density polyethylene net as core placed and heat-bonded between two nonwoven geotextiles).

During the construction phases it became evident that the stability of the vegetative soil to be laid on top of the geosynthetics package was guaranteed only for slopes having a much lower inclinations than the slopes to be built.

Only at this stage, when the geomembrane was already been installed in a continuo solution from top to bottom of the slopes through the central berm, a soil veneer reinforcement solution was studied to stabilise the top vegetative soil layer.

2.4.2 *The soil veneer reinforcement solution*

A reinforced erosion mat composite was used to solve the above mentioned technical problem. The presence of a double twisted steel mesh reinforcement inside the composite allowed to achieve a composite tensile strength of 47 kN/m (Figure 2).

Figure 2. The reinforced mat used to guarantee the stability of the vegetative soil placed on the lining package (membrane plus drainage composite).

The geocomposite was laid in between the drainage composite and the vegetative soil layer in order to reduce as much as possible the costs (increased from the initial forecast by the need of a soil reinforcement). The drainage composite had only one geotextile-layering filter instead of two as originally designed. Figure 3 shows the final solution.

The slope length was not constant and the strength required from the analysis calculation exceeded in some sections what available; in these sections the reinforcement was doubled to satisfy the equilibrium. Where the slope high exceeded 15 meters, the reinforcement was doubled for a length of 11 metres from the top of the slope.

Figura 3. Typical cross/section of the geosynthetics capping layers (geomembrane – drainage composite – reinforced mat).

Special care was due to the second slope anchorage to the intermediate berm. A layer of approx. 10 cm of soil was placed on top of the drainage geocomposite in order to improve the friction performances between the reinforcement composite and the drainage layer. On the reinforced mat was then laid a thick layer of vegetative compacted soil. The thickness of the layer placed on the intermediate berm ranged from 120 to 150 cm according to the slope height: 150 cm were used where the slope high was over 15 metres (Figure 4).

Figure 4. Soil ballast layer placed at the toe of the first slope in the intermediate berm.

The thickness of the vegetative soil cover was approx. 30-35 cm and it was protected against erosion phenomena by a straw-coco biomat. The original choice was not a biomat but a juta net; the change was due to technical reasons related to better performances expected from the biomat. The biomat guarantees better performances from the hygroscopic and thermostatic point of view and reduces the evaporation keeping under control the humidity level of the entire area. Tests done of areas protected with biomat showed a better behaviour against erosion events due to wash away phenomena.

2.4.3 *Green reclamation*

A study of surface runoff processes has been performed in order to achieve a good green reclamation of the area.

Instead of making diagonal and maximum sloping ditches (considered not affective and susceptible to erosion) it was decided to use natural water catchment lines, during construction work, reshaped and designed in order to allow estimated critical water discharge flowing. The shrubs plantation was increased (3000 instead of 1000 detailed in the 1rst design stage) in order to achieve an average rooted density of 3000-4000 gr/sqm against the usual 500 gr/sqm, which are characteristic of similar climatic condition.

The green reclamation was performed in two steps:

1) Seeding of a mixing skilled herbaceous species:
   - leguminous : Lotus, Medicago, Trifolium, Onobrichys, Vicia.
   - graminaceous: Festuca, Phleum, Bromus; some pioneer species were added like Inula ciscosa, Plantago, Bellis.
2) Plantation of woody pioneer vegetation or allowing for poor soil amelioration:
   - Leguminous plants like Spatium and Genista which by means of symbiotic relationships with bacteria (Rhizobium) allows for nitrogen fixation.
   - The Cornel (Cornus mas.) which produces a big amount of organic matter and has a high establishment capability: this are important features for stabilisation of covering soil layer.
   - Prunus spinosa, Phyllirea, Cistus, Pistacia lentiscus.

30% of plantation has been made with plants matching stable vegetated nearby sistes: Erica, Mirtus communis, Arbustus unedo, Cistus monsp., Pistacia lentiscus, Phyllirea, Rosmarinus, Lavandola, Ty

3 THE CONSTRUCTION STAGE

In spite of a geosynthetics package accurate design (ultimate state analyses had been done to check and verify the different package layers), the reinforced mat had a break in a small area – 500 sqm (Figure 5) on a full covered area of approx. 18.000 sqm. This happened after some heavy rains occurred during Spring 2000. The causes of this collapse have been deeply investigated with accurate back-up analyses before taking any action. The conclusion was that the collapse was possibly due to several factors like:

- The thickness of the layer that was deeper than supposed to be in the design stage ('in situ' investigations reported a thickness of the soil layer 30-40% thicker than supposed to be as showed in Figure 6).
- A decrease of the friction angle below the design value (set as usual to 12 degrees) due to the heavy rains occurred in that period.
- A possible increase of the weight of the soil due to his cohesive component.

Figure 5. General view of the collapsed area

Figure 6. View of the broken reinforced mat

The collapse of the mat occurred – in most of the sections - exactly at the end of the additional reinforcement confirming that the collapse was due to a lack of mechanical strength and – in few other sections – at different points in the middle slope length. A back-analysis at the break location confirmed the initial evaluations. More difficult was to understand the few breaks occurred at the middle of the mat (probably due to bad connections of different mats).

Established that the problem was not in the geosynthetics itself or in the design philosophy and that the solution was correct, the materials have been replaced.

In order to increase the safety of the most critical sections the length of the secondary reinforcement was increased for the whole length of the slope from bottom to toe. To reach the toe it was also necessary to build a ramp; the construction of this embankment reduced the free length of the slopes and increased the safety factor of the new sections. So doing the slope integrity has been quickly re-established (Figure 7).

Figure 7. The collapsed area after the rebuilding.

A second check of all the constructed slopes (18.000 sqm) has been made to verify their actual conditions taking into account the factors that caused the previous collapse of the small portion (500 sqm). The safety factor was anyway higher than 1.3 and no movements or problems have been reported in all the landfill sections.

The final results (Figure 8) achieved was excellent and the same solution has been applied in the design of a second landfill to be recovered in the same area.

Figure 8. Panoramic view taken from the close motorway of the reclaimed area.

4. CONCLUSIONS

The most interesting considerations can be done with reference the collapse occurred in relation with the design stage, the product performances and the installation phases.

The key problem at design stage is related to the identification of the interaction factors between the different geosynthetics. The interaction factors values vary in fact very much depending up on the different situations. Assuming a friction angle of 12° is generally correct but it is also evident that, in some circumstances, the value should be lower (8-9°). It is possible to use the less conservative value provided that the additional design hypothesis are correct and not underestimated.

The thickness and the "quality" of the soil placed on the reinforced mat are the next relevant issues:

- The thickness (especially when it is supposed to be thin) is difficult to manage and it is very easy to overload the geosynthetic;
- The weight and also the quality of the soil is not homogenous and – quite often – the characteristics are different from the once assumed. Changing in soil weight and quality can also increase the loads.

The reinforced mat used performed well and its behaviour was excellent. Furthermore the collapse was expected since the tstructure was overloaded. An interesting point that should be noted is that the use of a steel reinforced mat (not subject to creep phenomena) enabled the designer to have immediate evidence of the problem and to solve it during the construction phase when the contractor was still on site and not later on (probably during the following winter) when, according to the creep required time, the strength resistance of a polymeric reinforced mat would have reached the same ultimate tensile strength and the mat collapse would have occurred.

As a general consideration it should also be noted that the design of an erosion system, like the one typical of this application, is a real structural project and that the input data must be consistent with the real situation. In spite of this it is often common attitude to consider small variation of the slope high, layer thickness, geosynthetics and soii types as not relevant to the final performance of the erosion system. This poor attention to the above mentioned factors leads sometimes to local problems especially in those areas where the materials are more "stressed".

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