# Reinforced very steep wall 23 meters high built on a river bank in an industrial settlement in Lumezzane (Italy)

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ABSTRACT: The paper presents a case-history of a high reinforced steep wall with inclination angle of 80° built in order to enlarge the settlement of a new industrial area in Lumezzane, Brescia, Italy. The area on top of the retaining reinforced structure will be used as a vehicle manoeuvring zone and will also serve as a car park. The toe of the steep reinforced slope lies directly on the top of big cemented boulders bank of a mountain torrent. Due to the presence of water springs coming from the backfill, these first foundation layers had to be filled with gravel in order to have a good draining behaviour and fully wrapped with a high permeability filter geotextile. A number of drainage pipes have been installed through the bank in order to discharge the water coming from the drainage foundation mattress into the torrent. The use of a steep reinforced slope as retaining structure allowed to follow the shape of the mountain torrent with good aesthetic results minimizing environmental impact proving once again the flexibility of this system for this kind of applications and uses.

## 1 INTRODUCTION

The project deal with the execution of a reinforced steep slope inside the construction of a new industrial settlement in Lumezzane located in Bajone Valley near Brescia, Italy. The settlement is formed by a two floors building and it is situated along the versant slope on top of the mountain torrent Faidana. The torrent is flowing at a depth of about 30 meter under the level of the foundation of the main building along the south border of the area. A parking area contiguous to the building and located between the same buiding and the below torrent was needed for vehicle monoeuvring. Due to the limited space available, a very steep retaining wall reinforced with geosynthetic was the chosen solution by the designer.(Figure1)

A detailed site investigation with in situ and laboratory testing was performed. From a morphological point of view the area is presenting eluvial-colluvial deposit primarily silt-sandy-clay mainly covered with backfill soil of 1-5 meter thickness in the lower part and up to 15 meters in the upper part. Versant geological structure is based on a dolomitic and triassic limestone dolomitic formation of principal dolomite.

Due to the non regular shape of the bottom wall profile along the torrent and to the different morpho

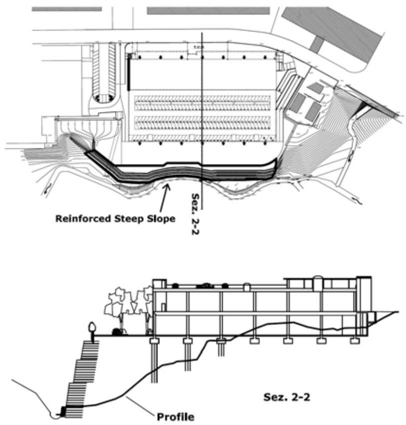


Figure 1. Plan view and typical cross section of the reinforced steep slope

logical and geological site situation, three typical cross sections have been studied to perform stability analysis. In particular two situations behind the reinforced steep wall along the bottom layer had been analyzed: in one the back slope at a distance of about 8,00 m was a firm and fractured rock mass while in the other situation the backfill soil was coming from the excavation of the upper part of the slope and from near aggregate quarry (Figure 2).

The retaining wall has been realized with three superimposed berms with 1,00 m bench between each:

- the lower berm has a varying height till 10,20 m due to the torrent profile and bottom slope and to be installed on top of the bank of the torrent built with very big cemented boulders.
- The middle height berm is 7,20 m
- The superior height berm is 6,00 m directly supporting on top the parking area

Stability analysis proved that the cemented rock-fill dam could be guaranteed only under limited backfill earth pressure. Therefore a low deformable structure in soil reinforced with geosynthetics, acting also a foundation block, has been installed behind the torrent bank laid on the firm rock soil. Its function is to support vertical load of the embankment with limited horizontal deformation to avoid down thrust against the boulder bank. In fact the structure will be not installed directly in contact to the boulders bank but with an empty spacing filled later with drainage material.

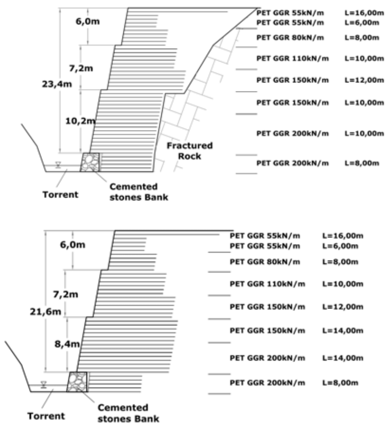


Figure 2. Cross sections of the two situations of the reinforced steep slope

## 2 DESIGN PARAMETERS AND GEOSYNTHETICS CHARACTERISTICS

The configuration of the steep reinforced slopes has been optimized by changing the strength and the anchor length of the geogrids with the wall height. Four types of PET woven geogrids have been used as reinforcement with ultimate tensile strength of 200, 150, 110, 80 and 55 kN/m with a constant spacing of 0,60 m between each layer. Lost formwork made with steel mesh (15 x 15 cm, 8 mm diameter) have been used in order to achieve uniform facing with an angle of 80°. A jute biotextile has been installed between formworks and geogrids to prevent erosion and 20 cm of fertile soil layer laid close the facing to help growing of vegetation

Also for the foundation block the wrap-around reinforced soil system has been chosen with 5 layers geogrids of 200 kN/m tensile strength, spacing 0,60 m for a total height of 3,00 m. Due to the presence of water springs coming from the backfill, these first foundation layers had to be filled with rounded cobblestones in order to have a good draining performance.(Figure 3).

Figure 3. Bottom foundation layer filled with rounded cobblestone wrapped with woven filter.

These layers were fully wrapped with a high permeability filter geotextile with an optimum opening size for preventing clogging and blocking of the filter with hydraulic mechanical properties. (Table 1).

| Filter geotextile | Mono-multi filament PP-PE woven HaTe C 50.002 | |
|---|---|---|
| Tensile strength long. (EN ISO 10319) | ≥ 45 | kN/m |
| Tensile strength trasv. (EN ISO 10319) | ≥ 55 | kN/m |
| Water permeability (EN ISO 11058) | $100 \times 10^{-3}$ | m/s |
| Opening size $O_{90}$ (EN ISO 12956) | 200 | µm |

Table 1. Woven filter characteristics

In order to collect and discharge the water coming from the slope inside the drainage foundation mattress and to prevent increasing of pore water pressure, a drainage system with network of draining tubes have been laid on the bottom, on the back part of the trench and connected with sub-horizontal tube passing through the boulders bank into the torrent. (Figure 4).

On the base of the geological investigation, boreholes and geotechnical testing and the backfill material available for the construction, the following soil geotechnical parameters, (Table 2), have been considered for stability analysis either for the foundation block and the above reinforced steep wall (RSW).

Table 2 . Design soil parameters

| Foundation block | γ (kN/m$^3$) | Φ'$_{des}$ (deg) | c'$_{des}$ (kPa) |
|---|---|---|---|
| Filling soil RSW | 20 | 36 | 0 |
| Firm,fractured rock | 23 | 35 | 20 |
| Backfill soil | 19 | 33 | 0 |
| Foundation rock soil | 25 | 35 | 100 |

| RSW | γ (kN/m$^3$) | Φ'$_{des}$ (deg) | c'$_{des}$ (kPa) |
|---|---|---|---|
| Filling soil RSW | 19 | 33 | 0 |
| Firm,fractured rock | 23 | 35 | 20 |
| Backfill soil | 19 | 33 | 0 |
| Boulder bank | 20 | 45 | 50 |
| Foundation rock soil | 25 | 35 | 100 |

High modulus polyester geogrids characterized by low deformation at high long term strength have been selected as reinforcement.

The allowable tensile strength of every reinforcement, LTDS, was calculated according to BS 8006 (1995) and the reduction factors have been supported by certified laboratory tests.

$$LTDS = \frac{f_{cr} \cdot P_{ult}}{f_{mr} \cdot f_m \cdot f_e}$$

The reliability of these value has a fundamental importance in the design as they directly affect the overall safety factor of the project. PET geogrids have characteristic shown in Table 3.

Figure 4. Drainage tubes passing through the boulders bank of torrent.

## 3 GLOBAL AND INTERNAL STABILITY

All stability analysis calculations were based on the limit equilibrium method using the computer software (RESSA, update 18, 2005 - Leschinsky) in accordance with Federal Highway Administration (Publication N° FHWA-NHI-00-043) recommendations.

Table 3 . Geogrids characteristics

| Material | Fortrac 200 | Fortrac 150 | Fortrac 110 | Fortrac 80 | Fortrac 55 |
|---|---|---|---|---|---|
| Description | PET Woven geogrid with polymeric coating | | | | |
| Tensile Strength long. (kN/m) (EN ISO 10319) | ≥ 200 | ≥ 150 | ≥ 110 | ≥ 80 | ≥ 55 |
| Elong. (%) | ≤ 12.5 | ≤ 12.5 | ≤ 12.5 | ≤ 12.5 | ≤ 12.5 |
| $F_{creep}$: | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| $f_m$: | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| $f_d$: | 1.06 | 1.06 | 1.06 | 1.06 | 1.09 |
| $f_e$: | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| LTDS (kN/m) | 98.98 | 74.24 | 54.44 | 37.49 | 26.72 |

$F_{creep}$: creep reduction factor (120 yrs)
$f_m$: reduction factor for extrapolation, manufacture (120 yrs)
$f_d$: reduction factor for mechanical damage (gravel - sand)
$f_e$: reduction factor for environmental effects (4≤pH≤9)
LTDS: Long Term Design Strength (120 yrs)

Stability calculations have been performed to check internal stability, (geotextile anchor length to avoid pullout of the geogrids, internal/tie-back and compound sliding planes, direct sliding – Spencer) and global stability for rotational failure mode (generalized Bishop). Calculations have been done on three typical sections at the maximum height considering on top a surcharge load of 20 kPa to simulate the traffic and/or parking of heavy trucks, obtaining safety factors FS ≥ 1.3 according to the Italian standards (Figure 5).

To be noted that the last upper geogrid layer has an anchor length of 16,00 m to act also as a subgrade reinforcement for the designed parking area.

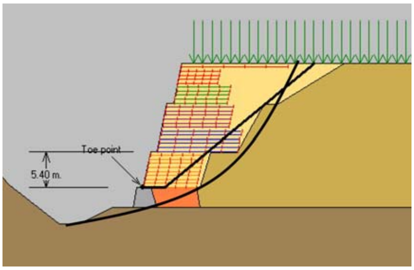


Figure 5. Stability analysis.

## 4 CONSTRUCTION

Works started in summer 2007 with the construction of the torrent bank with cemented boulders and the excavation in the lower part to create the space for the base of the reinforced steep wall.

Two affluents of Faidana torrent, already forced in concrete tubes for the urbanization of the area, are passing through the slope of the reinforced wall and entering into the torrent.

Figure 6. Construction phases

The flexibility of the reinforced soil system allowed to follow the squared shape of the tube laterally and on top keeping the tube in position without any problem and damage to the structure with a pleasant aesthetic effect.

Edges at both sides of the reinforced steep wall for the full height had to curve and to finish directly on the versant following the slope morphology avoiding any water infiltration of rainfall inside the body of the embankment.

Various phases of the installation of the geogrids and the impressive view of the wall after completion are shown in Figure 6.

Due to the important height of the structure and to avoid any further settlement accurate heavy compaction has been done. Normally at least 4-6 passes of the roller every 40 cm thick layer of filling were proved necessary to obtain the compaction degrees imposed by design (90% of maximum Modified Proctor density according to AASHO). Bearing plate tests have been performed regularly with the elevation of the wall to check backfill density.

## 5 CONCLUSION

The choice of the reinforced steep slope in this project was the ideal solution to minimize environmental impact in this valley environment and to solve few technical aspects came out during the design phase:

- reduce the active pressure against the cemented boulder bank of the torrent
- allow a very efficient draining system in the foundation layer with complete water discharge into the torrent
- best optimization of the limited space for the car parking area on top of the very high reinforced steep wall
- follow the shape of mountain torrent with good aesthetic results.

Observation of the geogrid reinforced steep slope during the first 12 months of service is clearly indicating no signs of relative settlements, face and horizontal displacements confirming the effectiveness of the adopted design choice and solution.


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