Reinforced steep slope design for a building area in Matera (Italy)

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ABSTRACT: To build a planar residential area on a hill in Matera (Italy), the designer planned the construction of an embankment with 3 to 12 m height by a reinforced steep slope. The geological and morphological situation and the buildings construction over the embankment, required several technical solutions to reduce the settlements and the front deformation of steep slope. Particularly, owing to a superficial clay layer with poor mechanical properties, the embankment was built on a reinforced concrete basement founded on piles. Moreover, to reduce the embankment movements were chosen a soil with good mechanical properties and a reinforcement with a high modulus. The very low deformations measured have confirmed the validity of the designing and execution procedures adopted for this reinforced steep slopes particular application.

1 INTRODUCTION

Since the attention to environment has been increasingly spreading throughout, building industry, too, has started choosing solutions involving works with a reduced environmental impact. Reinforced steep slopes, being in line with that growing need, have been increasing their being used often in replacement of the traditional reinforced concrete walls. The present case study describes a building intervention in Matera (Italy) carried out to build 40 multi-family buildings and consisting in the construction of a planar area of approx. 10 hectares along the slope of a hill which was partially affected by an impluvium. This design necessarily required a sub-planar area to be built and so it was decided to carry out a large embankment supported downhill by an approx. 200 m long reinforced steep slope with 3 to 12 m heights.

2 ARRANGEMENT

The intervention area average slope was approx. 12° with a total difference in gradient of approx. 60 m. In the central area there was a modest impluvium fed by two seasonal springs. The geology of the site is characterized by the presence of superficial silty-clay soils with frequent sandy layers resting on the bed rock formed of the Calcareniti della Formazione di Gravina (calcareous tuff from Gravina formation).

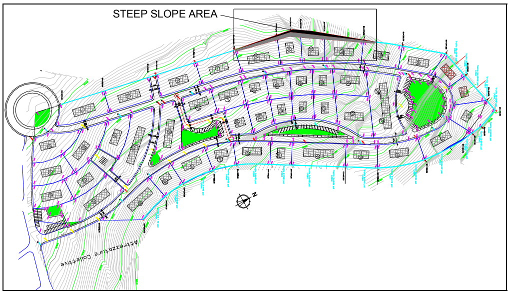

Figure1. Plan area

The intervention area is seismic.

3 GROUND INVESTIGATION AND TESTING

To define the geotechnical model a series of continuous logging drillings were carried out along with SPT tests and some undisturbed samples were drawn to be tested in lab.

Moreover, DPT tests were carried out to evaluate quickly and qualitatively the first soil metres mechanical behaviours. All surveys made it clear that silty-clay soils had different mechanical characteristics with undrained cohesion values c_u varying between 30 and 150 kPa. The bed rock was at 6 to 9 m depth with the water table at – 4,5 m from country plane.

4 DESIGN CHOICES

4.1 *Geotechnical model*

According to data entry and elaboration a first geotechnical model (figure 2) was defined. It was characterized by a reinforced steep slope with 3 to 12 m heights and a slope of 70° directly resting on silty-clay soils. Reinforced steep slope used in new embankments were formed of what locally called “tufina” (tuff) that is to say a granular material with good mechanical properties while for backfill soils it was planned to use silty-sand soils coming from excavations from another yard area.

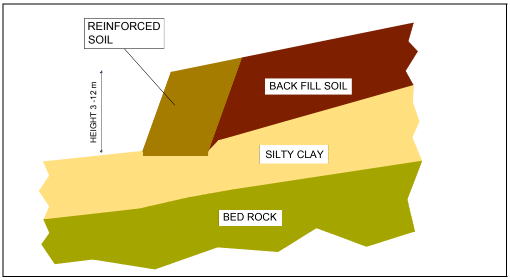

Figure 2. Preliminary geotechnical model

According to geotechnical tests on spot and in lab, the geotechnical parameters chosen for all soils types are those reported in table 1.

Soil Type	γ_{des} (kN/m3)	ϕ'_{des} (deg)	c'_{des} (kPa)	$c_{u\,des}$ (kPa)
Reinforced soil	19	35°	0	/
Backfill soil	19	28°	0	/
Silty Clay	19	23°	31	50
Bed Rock	24	45°	200	500

Table 1. Design soil parameters

Preliminary analysis made it clear that the silty-clay layer could run the risk of differential settlements. For this reason it was decided to build the reinforced steep slope embankment on a reinforced concrete basement anchored and founded on piles laid down onto the bed rock. Then it was defined a final geotechnical model according to figure n.3 plan.

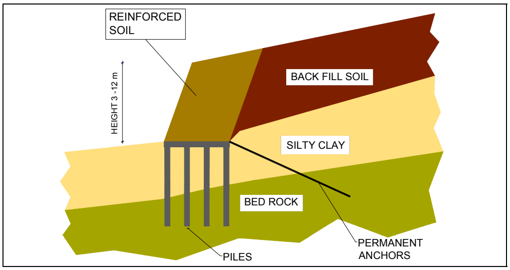

Figure 3. Final geotechnical model

Finally, we went to analyse the carrying out of a system of picking-up and conveying of waters coming from seasonal springs. Therefore, the plan proceeded by filling in the impluvium using gravel and non-woven and placing a conveying pipe passing under the reinforced concrete foundations to flow into the open air in the area before the work.

4.2 *Reinforcement choice and measuring*

Being a road and some buildings planned to be built over the reinforced steep slope, it was decided to establish a total deformation within 5% and a post-constructional deformation within 0.5% according to BS8006. Following such instructions, the use of a polyester welded geogrid with high modulus appeared to be the best choice. By examining the isochronous curves characterizing the chosen reinforcement and establishing the above mentioned deformations, it was observed that the available strength at 120 years equalled 55% of the ultimate tensile strength (UTS).

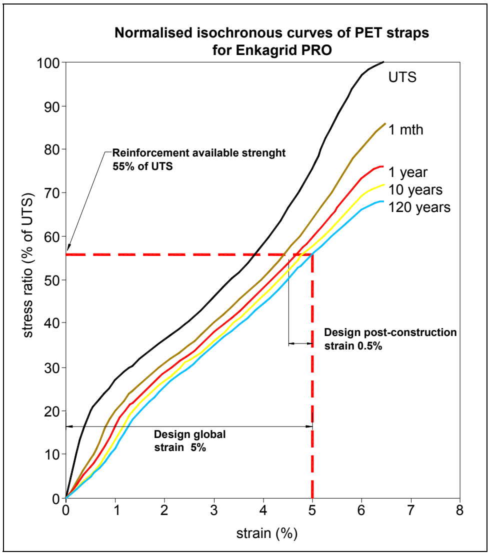

Figure 4. % Ultimate Tensile Strength (UTS) load established by design deformation (isochronous curves – Colbond)

Then, the partial safety factors, as reported in table 2, were chosen according to BBA Certificate n°03/133 and considering the soils to be used for the reinforced steep slope construction.

	design conditions	safety factor
Design life fm	120 years	1.10
Installation damage fd	Coarse gravel with sand	1.03 - 1.05
Environmental fe	pH 4.1-8.9	1.00

Table 2. Partial safety factors

4.3 *Reinforced steep slopes design*

The reinforcement type chosen, the real measuring was, then, taken into consideration by analysing all the potential strain mechanisms.

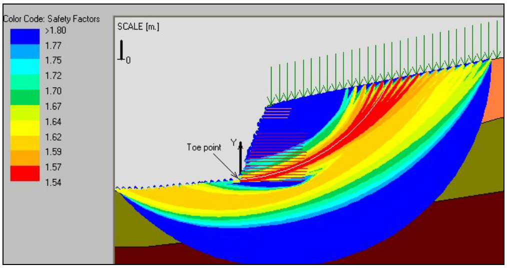

Figure 5. Global stability results - h= 12 m

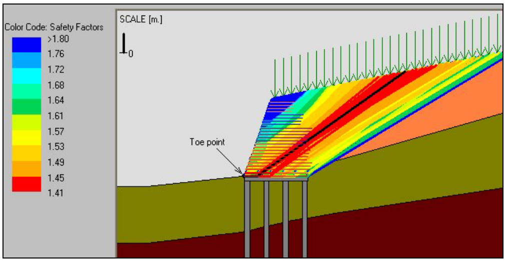

Figure 6. Translation stability results - h= 12 m

Starting from checking results, it was planned to use the here below reinforcements (see table 3), which were placed in 50 cm layers with different lengths.

Enkagrid PRO	40	60	90	120
Tensile Strength at ultimate – (kN/m)	40	64	98	120
Tensile Strength at 2 % strain – (kN/m)	17	26	42	48
Tensile Strength at 5 % strain – (kN/m)	33	51	81	87
Tensile Strength at 5 % strain after 120 years with safety factors of Table 2 – (kN/m)	19.41	30.48	42.86	57.14

Table 3. Geogrids properties

4.4 *Vegetation interventions on wall surface*

To favour a new vegetation flourishing on the frontal wall surface of the reinforced steep slope, already at first design level, it was planned to place approx. 500 seedlings of different autochthonous species.

5 EXECUTION

5.1 *Construction phase*

The construction started by carrying out the foundations piles and the conveying system of impluvium waters using a trench with gravel, non-woven geotextile and followed by a pipe. Then it was the time of the central reinforced cement basement filled with gravel and blocked by passive permanent anchors.

Photo 1. Foundations basement construction

Foundations and draining works finished, the embankment building began. The frontage was executed using the wrap around technique by placing a nylon geomat all around except for the first layers in gabions. The material high permeability made it possible not to place draining material on the back.

Photo 2. Phase of reinforced steep slope carrying out

During the construction, periodic tests on spot and in lab were carried out to control the used materials quality and the solidification level resulting from density tests on spot as well as from plate tests.

5.2 *Post-construction phase*

The reinforced basement construction finished, we went on to the plano-altimetrical monitoring over the more critical strip corresponding to the top height area measuring 12 m. Monitoring was achieved using 6 short pillars placed at the top and 4 optical prisms along the slope. 1 year measuring pointed out that there had been very modest movements leading to a progressive attenuation of displacements.

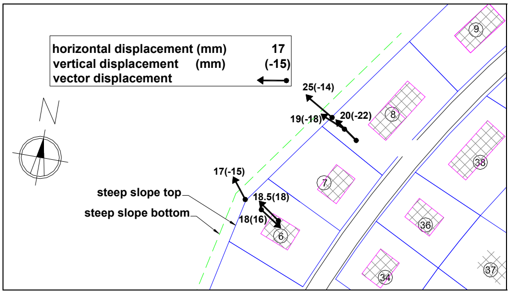

Figure 7. Points of monitoring and surveyed displacements

5.3 *Frontage vegetation*

To reduce the visual and environmental impact to a minimum, approx. 500 autochthonous species seedlings were planted. Moreover, the frontage was watered in a very dry summer period. All these careful choices enabled a rich and flourishing vegetation growing on the frontage.

Photo 3. Vegetation revival on reinforced steep slope frontage 1 year later

5.4 *Present situation*

After almost two years since the beginning of the embankment construction, the structure has fully achieved the required conditions. In particular:

- displacements have ended and structures construction has been started;
- the growth of a rich vegetation covering assures that building intervention of an excellent environmental insertion into the surrounding territory.

Photo 4. Buildings construction beginning

6 CONCLUSIONS

The work presented in this case study highlights how the reinforced steep slopes technique can be perfectly used in city building industry, too. The authors think that the good results achieved come from the careful design approach to the definition of the behaviours requested to the materials and to the continuous control of all feasible phases. Besides the specific geotechnical aspects, it must be finally considered that vegetation is a fundamental element if you want to achieve a good work insertion into environment.

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