REINFORCEMENT WORKS FOR THE SLOPE STABILIZATION: STANDARD AND NEW APPROACHES FOR THE USE OF MICROPILES AND ANCHORS

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ABSTRACT

The reinforcement works for the slope stabilization, natural or excavated slopes in rocks or soils, have developed in various directions. The technology is always researching new solutions for reducing the economic and environmental impacts and, at the same time, guaranteeing efficiency and the maximum improvement of long-term safety conditions.

After a brief overview of the reinforcement types most commonly used in our region, with particular care to the Vicenza Province (NE Italy), the paper present a short discussion on their most favorable applicability conditions and on their efficiency.

Then we present a new approach for using the soil nailing in the stabilization of medium deep landslides, analyzing the advantages offered by this new solutions, ! " # $%& '(%$) *+%$ +$%, . / '(%" ,*! 0 /$*! (. /1$# $! ,2-, in comparison with micropile structures and traditional anchors.

Finally, the paper introduces the studies recently started for improving the use of soil nailing as slope remedial works.

1. INTRODUCTION

The Vicenza Province, located in the Veneto Region (NE Italy), can be sub-divided into two geological domains separated by the main tectonic lineaments (Figure 1). One domain is characterized by elevations up to 700 m a.s.l. and low slope angles: the outcrops are volcanic rocks (lavas, pyroclastites and ignimbrites) overlain by eluvial and colluvial deposits of variable thickness. Numerous rainfall-induced landslides, mainly shallow soil slips, flows and rotational and translational slides, affect this domain: overall, the landslides here located represent more than 80% of slope movements in the Province. The other domain has elevations up to 1900 m a.s.l. and medium to high slope angles. Here the outcropping rocks are limestones and dolomite, affected by falls, topples, deep and complex mass movements: here, the landslides represent less than 20% of the total landslides in the area.

To give an idea of the high frequency of landslides interesting this province, we remember what happened during the last exceptional rainfall event in November 2010 (Floris et al. 2011). In two days, about 340 mm of rain fell on the area causing one of the most catastrophic floods in the last 100 years in the pre-Alps and piedmont sectors

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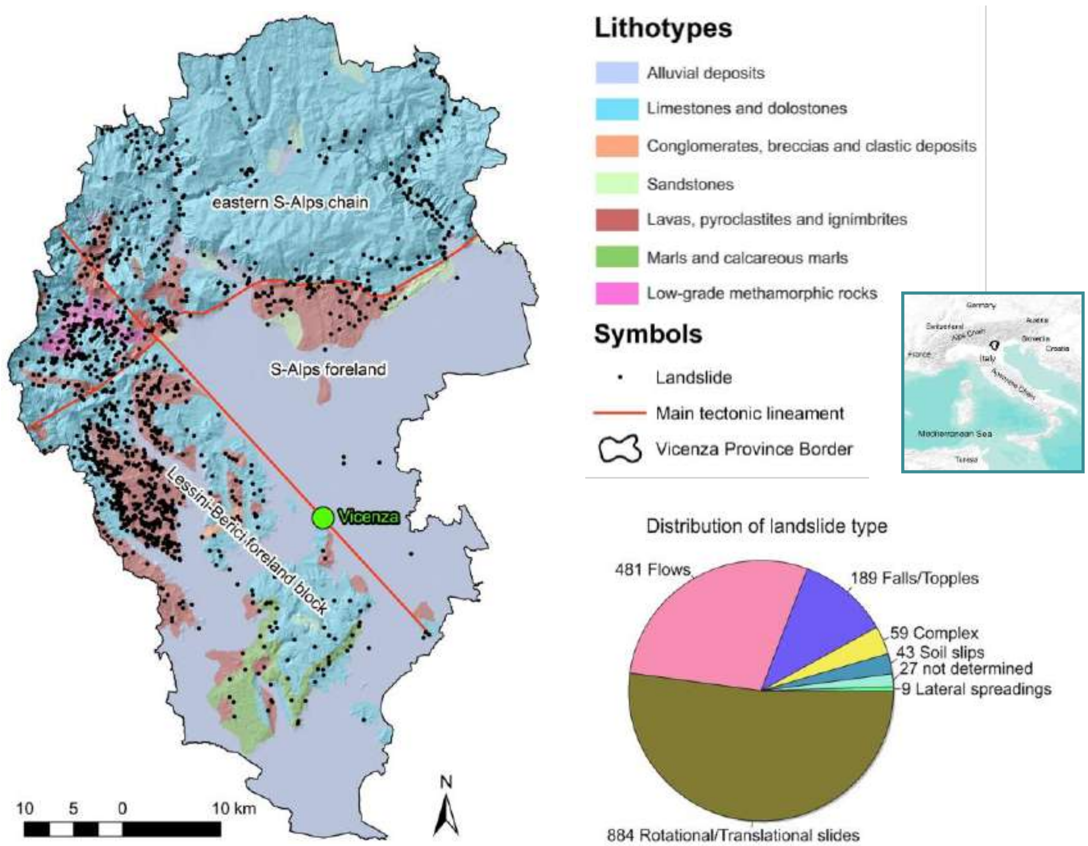


Figure 1. Geological map of Vicenza Province and landslide distribution in the area.

of Veneto Region. The intense rainfall triggered a huge number of mass movements in the Northern and Western parts of the Vicenza Province: the Soil Protection Division (SPD) received about 500 warnings of landslides, distributed over 20 municipalities of the Vicenza Province (Figure 2).

In order to determine the priority of intervention, after a field survey in the affected areas, the SPD realized a simplified landslide database, collecting, for each movement, data on geographical location, event date and time, kinematics, involved rocks, state of activity and, finally, resulting and potential damages.

As reported in Figure 2, all types of landslides occurred with a prevalention of rotational slides (49%) and flow phenomena (soil slip, earth flow and debris flow). The phenomena, both localized and widespread, involved only the debris cover in 70% of cases, the eluvial or colluvial layer in 28% and the rock formations in the remaining 2% of cases. The majority of phenomena had small to medium size, 46% and 36% respectively, and only the 4% of them were very large landslides. The 89% of mass movements caused damages to the road system, while in the 7% of cases private buildings were involved. The overall estimated costs for remediation works amount to about 80 millions of Euro.

Since the SPD has the job of managing the design and the execution of landslide remedial works, it has widespread experience in this particular sector of geotechnical engineering. Moreover, the SPD concerns itself with research of new technical solutions

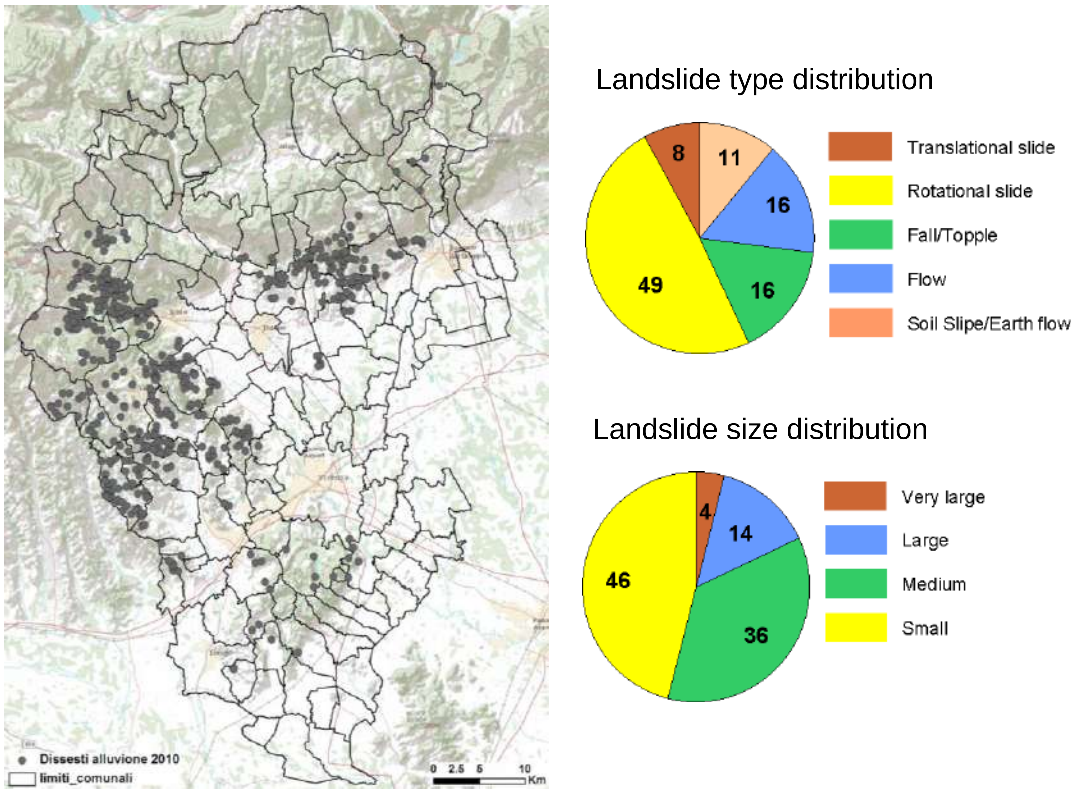


Figure 2. Distribution of landslides occurred after October 31 3 November 2, 2010, event.

in order to reduce the cost and the impact of interventions, increasing, at the same time, their efficiency on the short and long-term global slope stability.

Consequently, on the base of the experience gained by the SPD, here we present a comparison among some different reinforcing works usually realized in order to remedy the damages due to movements and improve the stability of slopes affected by landslide risk. Herein, we limit our overview to the reinforcement techniques, even if, in this region, it is common to realize also drainage systems, installed singularly or coupled with reinforcements. This choice is due to our aim to develop an evaluation of the advantages offered in this engineering sector by a new solution adopting the soil nailing for slope stabilization also on medium/large landslides.

2. TYPICAL REINFORCEMENT INTERVENTION ON SLOPE

Slope stabilization with reinforcements provides to increase shear strength or reduce the sliding actions along the slip surface with various types of structures: retaining walls, dowels, micropile systems, anchors, soil nailing, etc.

In Vicenza Province all kinds of wall are used: gravity or cantilever walls, gabion walls, reinforced earth walls and tied-back walls. As showed in Figure 3, the wall are used for stabilizing small size landslides, in slope regarding intervention, sometime coupled with a dewatering system (Ferrari, 2011).

(a) (b)

Figure 3. Examples of wall in Vicenza Province: a cantilever tied-back wall realized at Lusiana (a); a gabion wall in Valli del Pasubio (b).

Figure 4. Realization of a structural well in Frana Fantoni (Recoaro).

The isolated shear piles (dowel piles) are reinforced concrete cylindrical piles that pass through the landslide, anchoring with their lower end in the lowest stable soils or bedrock. They may be organized in various geometrical configurations: they are usually placed in single or double lines, or in circle line for obtaining structural wells. They help the stability because they increase the shear resistance along the sliding surface: they may be full depth shear piles but also buried shear piles that intersect the sliding surface without crossing vertically the entire moving mass.

Dowels are not suitable in all the slopes, because their construction requires the employment of very big boring machines. In Vicenza Province there are some examples of shear piles configured to obtain structural wells: for example, the structural well realized in 2010 for the stabilization of Frana Fantoni (Favero et al., 2010) in Recoaro village (Figura 4): it is a cylindrical excavation, temporary supported by braced micropile wall, with the internal surface subsequently covered with a cast-in place reinforced concrete wall.

Instead of dowels, it is more frequently adopted micropile structures (Bruce, 1988), for instance micropile walls or reticular systems (Figure 5), with or without

(a) (b)

Figure 5. Examples of tie-back micropile wall in Vicenza Province: a landslide in Posina (a); a detail of micropiles easel with bar as reinforcement (b).

(a) (b)

Figure 6. Anchor connection plate during installation (a); a soil nailing with flexible face in Vicenza (b).

anchors (Stevan, 2011). Their major diffusion is due to various reasons: they need small boring machines; the installation is easy in quite all types of soils and rocks; when micropiles are used in groups, with their external end connected with a beam and some of them inclined with respect to the vertical position, the shear and flexural strength of the group increases a lot.

In Figure 5b it is possible to note that the standard steel tube adopted as resistant element in micropiles was substituted by the self-drilling bars typically used in soil nailing. This substitution is due to the economic and technical advantages provided by the self-drilling technique:

1) the bars, having a minor external diameter with the same steel section, require a smaller borehole and allow to get a thicker grouting cover for the corrosion protection of bars;
2) the self-drilling bars do not require the pre-drilled hole, thus speeding up the in-situ building up of the structure.

For stabilizing a soil slope or fractured rock mass, anchors are usually installed in connection with an external retaining structure (wall, beam, net, micropile wall, etc.) (Juran and Elias, 1991) which distributes the anchor load on a large soil area avoiding soil punching (Figure 6a). Since they are pre-stressed (active reinforcement), they need a short-term performance verification (load test after installation), but also a long-term monitoring with a consequently higher maintenance cost. The main advantage of anchors is that they have no limits in length, of course considering the conventional applications, thus they may be used also in medium and deep-seat landslides.

Finally, the soil nailing is an evolution of reticular system of micropiles (Lizzi, 1980). It is prevalently applied for retaining excavated slope (as temporal or final support), but also in slope stabilization (Elias and Juran, 1991; Berardi, 1997, FWHA, 2003). The nails are generally not pre-stressed (passive reinforcement) and consequently they do not need particular maintenance care.

Externally, the soil nailing bars are connected to plates and to a facing that, according with the European code (prEN-14490, 2010), may be rigid (formed by pre-cast or cast in place concrete plate, spritz-beton, etc.) or flexible (i.e. a rigid steel net) or soft (i.e. a very flexible steel or plastic net). In slope stabilization works, soft or flexible facing are used, because they allow plants and grass to grow up with limited environmental impact (Figure 6b).

2.1 Economical comparison among different types of interventions

In order to compare the economical efficiency of interventions we analysed the possible interventions on a reference slope, selected as a typical instable slope of the Province.

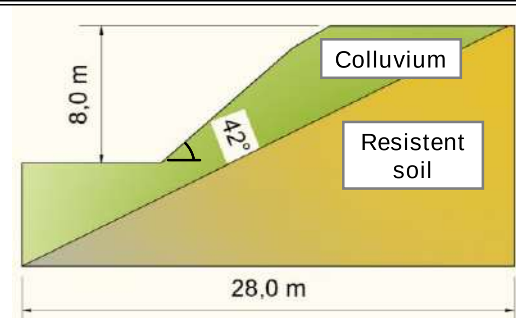
The geometry of the reference slope is outlined in Table 1, while Figure 7 shows the various interventions considered in the analysis and the results of Limit Equilibrium (LE) analysis performed for each case with Fellenius method. Table 2 summarizes all the sizes (height of wall, base width, depth of micropiles, spacing, etc.) of reinforcement structures, together with the safety factor obtained in the LE analysis and the cost of intervention.

The design of interventions verified both the external and internal stability conditions as required by the Italian regulations: for instance, the concrete wall has to satisfy the moment equilibrium, the horizontal sliding, the load capacity for the foundation and the global stability, but also the limit states for the reinforcement rod inside the concrete. The external limit states analysis was performed reducing the resistance parameters with the partial safety factor γ_M equal to 1.25 according to Italian and European code (NTC, 2008, Eurocode 7, 2007, Eurocode 8, 2008). Moreover, having supposed the intervention executed in Cornedo Vicentino, a village at North of Vicenza, a dynamic load corresponding to the third seismic class, a subsoil type C and a topographic coefficient equal to 0.72, was applied adopting the pseudo-static method.

In some cases, the equilibrium requirements keep to lower the structure foundation with the consequence that the safety factor becomes overmuch higher than the minimum value required.

The cost of each intervention was obtained considering a structure with a front 30 m long and the current price of materials and workings in the Vicenza Province.

Table 1. Reference slope and geotechnical parameters of soils.

Formation	Type of soil	/ (kN/m^3)	c' (kPa)	″ (¡)	
Colluvium	Clayey Silty Sand	18	0	28	
Resistent soil	Gravel	19	0,1	38	

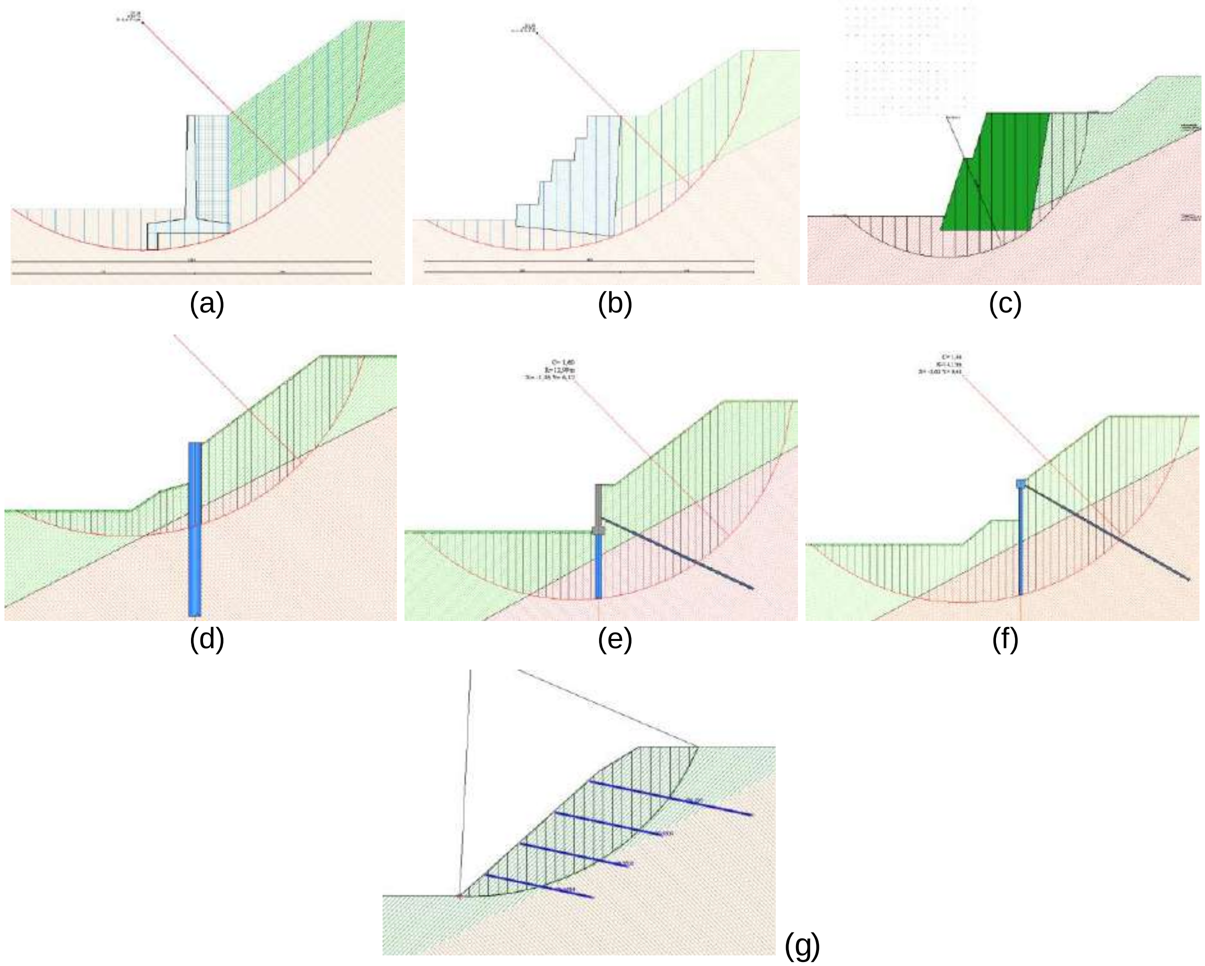


Figure 7. Interventions for the reference case: cantilever concrete retaining wall (a); gabion retaining wall (b); reinforced earth wall (c); line of drilled piles (d); tie-back micropile wall (e); tie-back wall with micropile (f); soil nailing (g).

From the comparison, we note that the soil nailing and reinforcement earth wall are the cheapest solutions, followed by the wall founded on micropiles. The soil nailing costs less than half of the gabion wall price that is the highest, more than dowels.