REMEDIAL WORKS AGAINST DEBRIS FLOWS AFTER THE 2000 FLOODS IN VALLE D'AOSTA

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ABSTRACT

In the Aosta Valley the flood event of October 2000 will be remembered as one of the heaviest events occurred over the last 250 years, in terms of destruction, loss of human lives, magnitude and spreading of the morphological changes on the territory.

Landslides, mudflows concentrated on the mid reaches of the main valley resulted in up to millions of cubic meters of debris flows which caused to the villages of Miseregne, Fenis, Rovarey and Nus serious threats to the safety of the houses and the nearby infrastructures. After the event, recovery works took place in the following year. They included, from the uphill side downwards, flexible catch fences and a combination of gabion retaining works perpendicular to the main slope for consolidation and drainage purposes. In order to harmonize these structures with the surrounding environment, soil bioengineering practices like the incorporation of vegetative pockets followed by hydro seeding treatments were used. On the lower side, where the gradients are less steep, the soil surface was cleaned, and just graded and seeded. At the toe of most sites, reinforced soil embankment barriers were built with the purpose to deflect future mudflows reaching the valley bottom. They were chosen due to their ability to incorporate vegetative soil allowing a naturally green face.

In the following years the recovery works in the Aosta Valley were subject to constant monitoring from the local authorities. Results have been satisfactory and encouraging, because they show that the principle of using different type of structures from the top of the hillside downwards, is a fundamental issue when dealing with vast areas subject to unpredictable and hazardous debris flows. This project is deemed of useful guidance to the engineering community when dealing with similar project scenarios.

Keywords: Debris flows, landslides, soil bioengineering, ecological systems

BACKGROUND

In the Aosta Valley the flood event of October 2000 will be remembered as one of the heaviest events occurred over the last 250 years, in terms of destruction, loss of human lives, magnitude and spreading of the morphological changes on the territory.

The effects were by far worse than two previous flooding episodes of September 1993 and July 1996.

Further to the exceptional rainfall occurred on October 12th through the 16th, equivalent to 28-55% of the yearly average precipitations, with a peak in Cogne up to 65%, where 454 mm

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were recorded, a vast region of the territory went through a geological rejuvenating particularly relevant in some watersheds.

Landslide occurrences concentrated mainly among the mid reaches of the main valley.

Particularly relevant were mudflows in the area near the village of Fenis, with detachment of the vegetative cover due to the presence of large heavy debris, hence resulting in a vast flooding of the conoid.

Superficial landslides were followed by large debris flows ranging from few thousands to millions of cubic meters, with serious threats to the safety of the housing developments and the nearby infrastructures. The villages hit by the most severe damages were Miseregne, Fenis, Rovarey and Nus. The magnitude and the effect of such deep landslides would not be so remarkable if the mid October rainfall event would not be preceded by the heavy rainfalls of September 28 till October 1st over the whole north western side of the alpine region, reaching up to 200mm rainfall precipitations on the valley bottom. This kept the soils in the whole subsurface hydrographic net in a saturation state, resulting in a high risk of instability as it occurred two weeks later. Following are few images (Figs. 1-4) showing details of the damaged areas right after the October 2000 flood. The width of the landslide conoid was variable between 30 and 80 m in most areas.

Fig. 1 : Oct. 2000 – Miseregne – view of main landslide from downhill side up

Fig. 2 : Oct. 2000 – Miseregne - View of main landslide from the uphill side down

Fig. 3 : Oct. 2000 – Miseregne - View of main landslide from the uphill side down

Fig. 4 : Oct. 2000 – Nus, house hit by the debris

OVERVIEW OF THE INTERVENTIONS

Design and planning of the recovery works started in March 2001.
The reconstruction started in the same year and was completed in 2002 for the most part. The area subject to the largest damage was Miseregne. Depending on the location on the slopes, several treatments were used for the recovery works.
Starting from the uphill side downwards, the interventions included a combination of various consolidation works (Fig. 5).

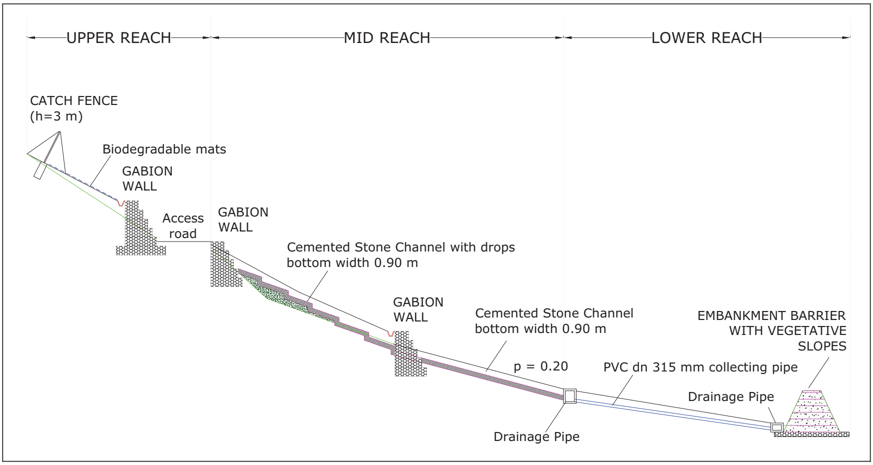

Fig. 5: Typical longitudinal profile scheme of the recovery works

The upper reaches

On the top hill side with the gradients steeper than 20%, a first line of protection was made by flexible catch fences to prevent the large rocks from falling down from the top of the hillside were used (Fig.6). These light structures were placed as close as possible to areas where large boulders may dislodge from the slope. In such manner it was anticipated that the maximum energy they will have to withstand will be moderate, since chances that boulders may travel a long distance before their impact against the fence would be low. Additionally, during the flood of October 2000 it was observed that large boulders, detached from the upper sections and rolling down the slope, had magnified the devastating effect of the debris carried by the flow. By preventing large boulders to roll down the slope with the fines, should an event of such magnitude occur in the future the amount and the impact of the debris reaching the bottom of the valley would be drastically reduced. Furthermore, the possibility to separate the large debris on the uphill section will allow an easier maintenance of the structures in a future event. The presence of an existing haul road, once reopened to the traffic, allowed to access the upper section of the damaged slopes and to install the flexible barriers with relatively small efforts.

Fig. 6 : Detail view of a flexible catch fence

Downhill from the first barrier line of catch fences, biodegradable natural fiber mats and geomats were used to prevent surface erosion, and favor fast vegetation regrowth in the damaged areas were also used, followed by a hydro seeding treatment (Figs. 7, 8).

Fig. 7: Upper reach of the conoid,
Biodegradable mats and hydro seeding

Fig. 8: Upper reach of the conoid,
Turf reinforcement mats and hydro seeding

The mid reaches

From the middle reaches downhill (with gradients approx. between 10-20%), a series of gabion drainage works, integrated in a network of collectors, was used. Eventually a last barrier using reinforced soil embankments was used as the ultimate protection barrier, to deviate the path of future debris flows to a safe area far from the housings.

Since debris flows are originated by the formation of an unstable cortical layer of saturated soil, in most cases remediation measures shall include adequate drainage systems to ensure that the soil will still maintain its natural shear strength above the stability threshold.

To reestablish adequate drainage and geotechnical stability to the surface on the mid reaches, a series of gabion retaining structures was laid perpendicularly to the main gradient line. In order to harmonize these structures with the surrounding environment, vegetative pockets using jute netting followed by a hydro seeding treatment were also applied (Figs. 9, 10).

Fig. 9: overview of gabion drainage works

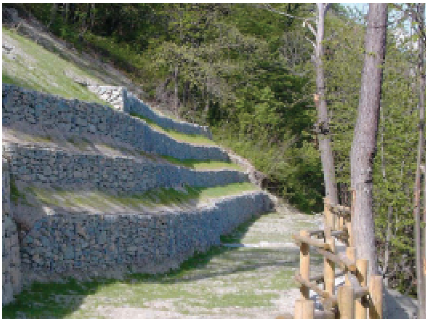

Fig. 10: view of the vegetative pockets

Gabions were chosen by the landscape engineers because of their ability to combine three main features in one system: 1) the strength to resist to the external forces due to the combined effect of the rock confined within the steel basket, 2) the high draining capacity due to their porous structure which prevents hydrostatic pressures from building up against the structure behind the wall, and 3) the ability to blend with the natural environment.

The presence of voids inside a component made of solid natural rock, makes these structures suitable for the incorporation of vegetative systems. During installation, on the outer side of the gabion structure a series of vegetative pockets were installed. This technique consists in unrolling a strip of jute netting in a channel like shape longitudinally to the gabion wall (Figs. 11, 12).

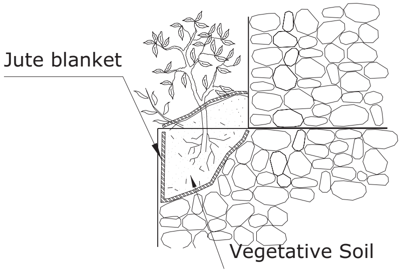

Fig. 11: detail of vegetative pocket

Fig. 12: view of vegetative pocket

In such way the jute will work as a confinement for the vegetative soil which will be then filled in. Once soil filling is complete and leveled to the top of the gabion course, the jute on the upper lateral sides is folded and the vegetative pockets are closed.

A drainage trapezoidal channel made with masonry cemented rock was laid in the center sections to convey the rainfall run off along the maximum gradient line (Fig.13). Alternatively for some areas, in order to control the flow conveyance, lateral timber piles (obtained using the logs from trees dragged by the flow) and drainage works were also laid in a fishbone pattern perpendicular to the flow direction (Fig.14).

Fig. 13: view of the drainage channel

Fig. 14: view of alternative drainage works

The lower reaches

Ultimately, on the lower side, where the gradients are moderate (less than 10%), the soil surface was cleaned, and just graded and seeded.

At the toe of most sites, as the last line of protection works, a series of reinforced soil embankment barriers were built. Their purpose will be in the event of future debris flows, to act as a passive barrier diverting mudflows on a safe sedimentation area at a safe distance away from the nearby housings. The morphology of the territory in the region is such that gradients vary very rapidly in a short distance (from steep to moderate) generating high risks of debris flows and landslides. In any event the landscape engineers decided that a safety barrier needed to provide protection to the ever increasing community living in the area at the bottom of the valley. The overall dimensions of the embankment, 4.5 m high, with slopes at 65 degrees, and a 2 m top width, were choosen to properly withstand the impact load of the debris for a design event equivalent to the one observed in October 2000.

The reinforced soil embankment barrier

The embankment barrier consists of a reinforced soil structure made of several layers with 0.73m vertical lifts of continuous steel mesh, wrapped around on the front face on both sides. Units are connected together prior to soil filling and compaction, proceeding by successive strata until the top of the embankment is reached. Units have different sizes to match with the trapezoidal cross section. The cross section is reported in Fig.15.

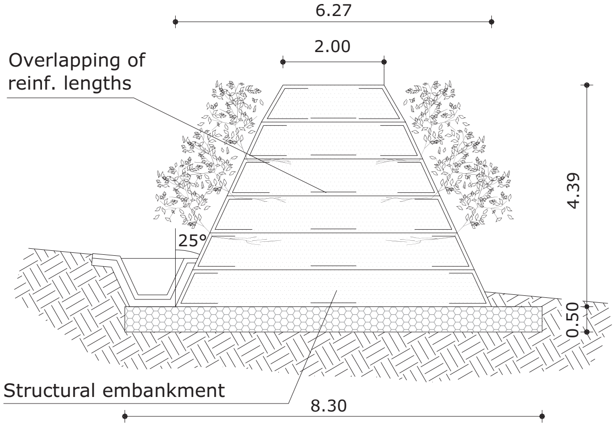

Fig. 15: Typical cross section of debris flow embankment

The embankment overall dimensions are 4.39 m in height, 6.27 m as the base width, 2 m as the embankment top width. Slopes are at 65 deg to the horizontal on both sides, allowing an effective hydro seeding treatment on both faces. This will ultimately favor the formation of a dense vegetative cover on the surface resulting in both an overall improvement of the aesthetics as well as in a better structural resistance.

The structural fill is made of granular material with high permeability, following A2-4 and/or A-2-5 (according to AASHTO classification). Filling and compaction operations were done using conventional earth moving equipment, at 250-300 mm lifts.

The embankment foundation is made by a 500 mm gabion apron (Fig.16), which will provide further draining capacity to the whole structure. A small channel on the uphill side lined with an antierosive geomat was included, with the purpose to catch all the surface runoff and drain it away.

Fig. 16: Rovarey, deflecting wall at the beginning of construction

Fig. 17: Rovarey, deflecting wall at end of construction

Advantages of building reinforced soil embankments were twofold: a) compared to conventional earth filled embankments they require a limited base width (sloping the sides at 65 degrees) hence a lesser amount of fill (Figs.17, 18), b) due to their ability to incorporate vegetative soil they allow a naturally green face to develop along their slopes which will soon turn the structure to blend with the natural surrounding (Fig.19). Furthermore, the vegetation growth will provide additional strength to the embankment through the rooting and the overall vegetation establishment. Appropriate drainage measures were also used to ensure the stability of the embankment's foundation.

Fig. 18: Miseregne, openings to let the flow through without pressure build-up

Fig. 19: Nus, deflecting wall at downstream end

The design of debris flow embankments was made assuming they shall withstand the dynamic impact generated by a colliding mass (Kar, et al). This assumption, although conservative in its whole, was chosen due to the absence of specific tests and of a more accurate numerical simulation method.

The Kar's theory used, assumes that penetration of a mass impacting against a wall barrier is given by:

$$Z = \frac{27183}{\sqrt{Y}} \cdot N \cdot \left(\frac{E}{E_s}\right)^{1.25} \cdot \frac{P}{d^{2.31}} \cdot \left(\frac{V}{1000}\right)^{1.25}$$

Where $Z = (z/2d)^2$; if $z/d \leq 2$ $Z = (z/d - 1)$; if $z/d \geq 2$

and
Y = soil compression resistance
N = shape factor (1 very sharp – 0.72 flat)
E = elastic modulus of rock [kN/m²]
Es = elastic modulus of steel = 206850 · 10³ [kN/m²]
P = weight of rock = 2000 [kg]
V = impact velocity (horizontal component)

The soil compression resistance is assumed based on failure criteria proposed by T.Kawamura for reinforced soils

$$\tau = c + \frac{P_r}{A_s} \cdot (\sin\vartheta \cdot \tan\phi + \cos\vartheta) + (1+\beta) \cdot \sigma_n \cdot \tan\phi$$

where
ϑ = failure plane ref. to horizontal
ϕ = soil friction angle
β = 0.2 ÷ 0.4, confining factor, to account for the resistance to expansion induced in the granular fill

Velocities considered in the analysis are 20 and 30 m/s, assuming average values for landslides are in the range of 10 ÷ 30 m/s.
Results show that, for the assumed energy and dimension values, max penetration values of 1.8 m were obtained; taking into account the conservativeness of the Kar relationship, max penetration values in the range of 1-1.5 m are expected still with a safety margin against breakthrough.

CONCLUSIONS

Since the year 2001, the training works of Fenis, Miseregne, Rovarey and Nus in the Aosta Valley were subject to constant monitoring from the Regional Authority (Figs. 20, 21).

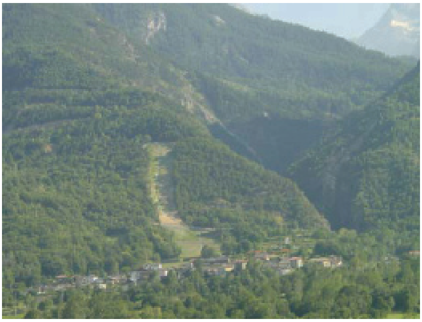

Fig. 20: 2002, aerial view of the Miseregne area.

Fig. 21: 2002, Rovarey, view of a vegetated barrier

Results have been satisfactory and encouraging. They have shown that the principle of diversifying the type of structures from the top hill down is fundamental when dealing with vast areas subject to unpredictable and hazardous debris flows. Another positive reason is that all structures used were particularly suitable for incorporation of soil bioengineering techniques. This aspect was fundamental to provide a sustainable ecologically balanced recovery. In this regard all the recovery works demonstrated the ability to blend with the surrounding environment, soon reestablishing the original and natural wildlife of the valley. Particularly successful in this regard were the vegetative embankment barriers where vegetation took over right after the first season.

Most structures chosen required minimal use of artificial material. They were designed with the engineering principles to combine the geotechnical and hydraulic stability with the modern environmentally balanced practices of soil bioengineering.

Over the last few years, the ever increasing occurrence of debris flow natural disasters in Europe, has raised the concern among the engineering community on how general guidance shall be provided for a sustainable environmentally balanced approach, in order to correctly address these project scenarios, or at least to provide a sensible engineering guidance in this regard.

Since technical literature on debris flows is still uncharted for the most part, it is believed that engineers could start learning from the field experience, by closely monitoring the environment where structures have been installed. This will ultimately allow to gather further data on how tests should be performed and to calibrate the field empirical results with the future laboratory research.

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