THE SECOND WORLD LANDSLIDE FORUM

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The case history of the Bagnaschino landslide, from Early Warning to site specific rainfall threshold

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Abstract
The highway n° 164, in 1994, was struck by a complex composite landslide activated in Bagnaschino (Torre Mondovì, Cuneo) due to flood events. In order to continuously monitor the stability conditions, the Cuneo County established a borehole monitoring plan in 2008 with DMS column 60m long. DMS (patents CSG Srl Italy) is a multiparametric system for the stability monitoring of slopes, excavation fronts and engineering works; the column is like a spiral cord composed of a sequence of hard tubular modules connected to each other by special flexible junctions. Correlation between DMS column and rain data allowed identifying critical events that have reactivated the landslides, along the sliding surface at 7m blg, allowing the adoption of preventive intervenctions (closing the road during the March 2011 rain event). Moreover with the DMS system was possible to calculate the site specific rainfall threshold curve that shows the limit stability condition related to the rain intensity and duration.

Keywords: complex composite landslide, early warning, DMS monitoring, site specific rainfall threshold

Introduction

The study area is in the Municipality of Torre Mondovì, Cuneo County, Piedmont Region. During the flood event occurred in 1994 the highway n. 194 was seriously damaged by a composite landslide activated in Bagnaschino site. In proximity of km 1+400 the landslide invaded the carriage way (Fig 1).

Figure 1 : Aerial photo in 2000

The landslide is a composite type, with a flow area at 5-8 mbgl and a deep creep at 30-40 mbgl. The estimate area is about 150.000m² with a volume of 1.2M m³. The element at risk is the Regional highway S.P. 164 and a potential lake formation.

To monitoring the area was developed an Early warning system composed by one DMS column and surface systems.

Geological setting

Basic's geological data are summarized in the sheets " Cuneo" (80) and Boves (91) of Italian's Geological Map (1:100000 scale) and in the sheet "Gap" of French's Geological Map (1:250000 scale).

On the basis of the mentioned cartography, the test area, affected by the geological instability, implicate materials belonging to the Axial Perm Carboniferous in particular gneissic, sericitic and filladic schists; sericitec quartz, generally paragenesic rocks.

Figure 2 : Photograph of the landslide in 1994

We observed, during the inspection, wide outcrops of prasinite and ofiolites. Being geomechanically rigid rocks, this heaps suffered a tectonics of disjunctive type, resulting in more points very fractured and predisposed to an aggressive action of weathering and to a raising distension.

Geomorphologic setting

The Geomorphologic structure of the whole valley bottom of T.Casotto and of the underlies slopes, results very conditioned by the litology of the bedrock and especially from his tectonical grade. So in the sector which structure is made by high tectonized rocks and/or high schistose (which appear covered by an abundant debris and soil), the valley bottom is quite large and the form of the reliefs are steep, whereas, in the zones where the bedrock of gneissic rocks or amphibolites rocks is present we have very steep scarps, and the valley bottom is narrow and the riverbed is embedded.

In many areas of these side' sectors we notice evident indications of deep gravitative morphogenesis (crowns and scarps, zone of accumulation of large paleoslides) which lead to suggest that the current slopes are in a condition of limit-equilibrium and are predisposed to slow movements or to run out processes, facilitated or caused by the temporary arise of triggering factors (large water's infiltrations, pronounced river erosion at the foot)

Lito-stratigraphics characteristics

On the basis of the geotechnical surveys, the stratigraphy of the landslide area (the upper part) is made by a considerable power (20 -30 m) of heterometric and heterogeneous debris in an abundant sandy silt and clayey matrix, with a low permeability primary porosity and endowed a high water retention and imbibition.

These materials lay on bedrock, which is highly weathered, intensely fractured and clayed, given by laminated micaschists, overlapping to metabasites and prasinites, highly weathered and fractured, no mapped in the geological maps. During the drillings several levels of perched water table were found, generally included in the most superficial levels, and the crossing of the bedrock generated a lot of problems because of the lost of the circulation caused by the highly fractured system.

The movement affects the recently reactivated portion, due to an alluvial event, of a biggest deformation of the slope of D.S.S.G.D type. The trigger of these movements is generally due to several factors; for the big Paleoslides of Bagnaschino the glacier decompression, after the withdrawal of the quaternary ices, and the presence of tectonically dislocations and fragile deformation, due to the presence of faults, had a crucial role.

Description of the DMS analysis

In order to monitor in continuous the stability conditions, the Cuneo County established in 2008 a slope monitoring plan with DMS system.

The monitoring system is composed by n.1 multiparametric DMS column, 60 meter long, installed in a borehole conditioned with an inclinometric pipe. The system is linked respectively to a local control unite, with its solar power supply, and a GSM transmission system for the collected data.

The column is composed by a series of 60 modules stainless steel AISI 304 containing transducers and digital electronic, linked by special joints, having the necessary freedom degrees for the type of measurement required, allowing the single unite to adapt to the characteristics of the borehole and to the movements of the landslide, preserving the azimuthal direction compared to an external reference system.

The instrumentation was installed in 28.10.2008 and in the same day linked to the monitoring centre by the GSM network (Fig 3).

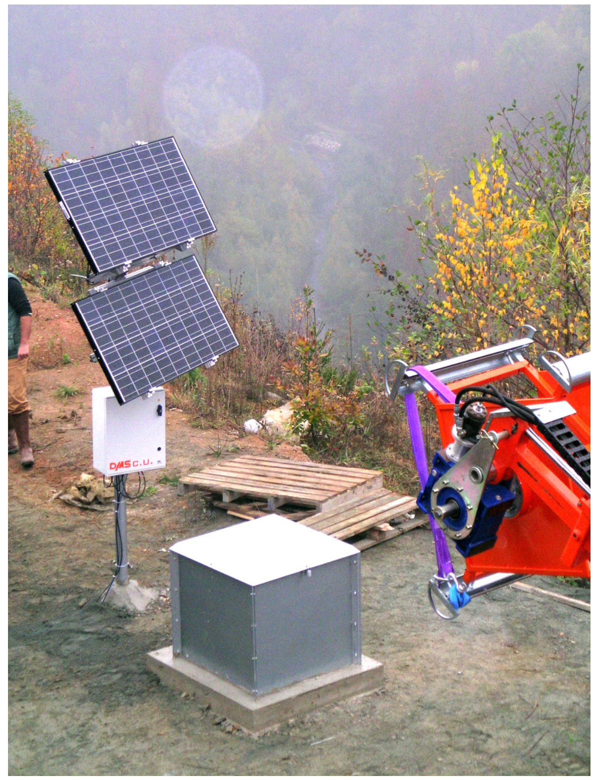

Figure 3 : DMS system installation completed

The modules contain 60 biaxial digital inclinometric sensors (range ± 20°, resolution 0.005°), 1 piezometric sensor (range: 0-100 psi, resolution 1cm), 60 temperature sensors (resolution 0.1 °C).

Data acquisition is continuous (24/24 h) checking for the warning every minute, and information is recorded in a data base every hour. The remote control station checks the system automatically through G.S.M. remote data transmission.

Correlation between DMS column and precipitation data allowed to identify critical events that have reactivated the landslide on the sliding surface at 7 m blg, with direction 30° NE. During the observation period it was possible to monitor in continuous different kinematics and different weather conditions.

DMS system allowed to investigate 5 triggering events and their relative period of stasis, with a clear delay time after rain events or snow melting (Fig 4,5).

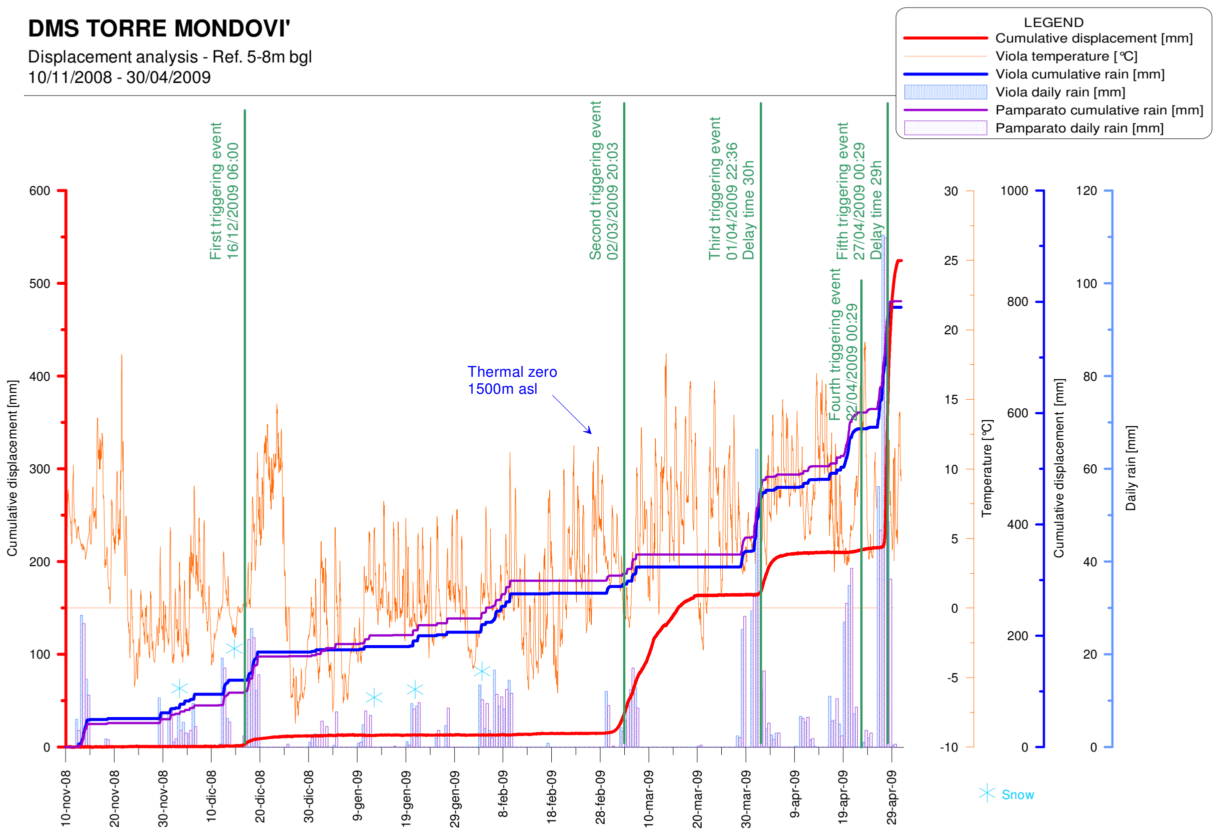

Figure 4 : Triggering events

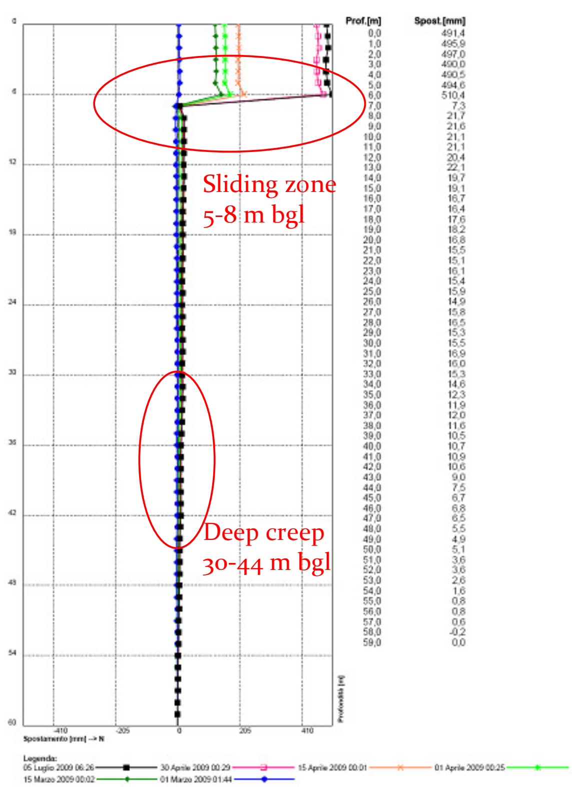

Figure 5 : Displacements during the events

The following describes the characteristics of each event:

- *First event*: on 28th November 2008 there was the first snowfall (one of the most intense of the last century in the area) that was followed by some rainy days and finally by another snowfall on 13-19th December. In the same days there was a temperature rise that caused the partial snow melting and subsequently the first movement read by DMS column.
- *Second event*: on 1st March 2009 there was a light rainfall following by a strong temperature rise (thermal zero at 1500 m asl) that caused the second landslide activation on 2nd March 2009 at 20:03, 37 hours after the rainfall beginning.
- *Third event*: on 31st March 2009 at 06:00 a strong rainfall began and lasted for some days. After 30 hours, the landslide moved.
- *Fourth event*: this event is linked to more rainfalls occurred in the days 16th-22nd April 2009 and is different from the previous events because of a lower movement velocity (displacement about 10 mm).
- *Fifth event*: on 26th April 2009 the strongest spring rainfall started and after about 29 hours (27th April, 08:00) the landslide moved. This heavy rainfall lasted for some days: the cumulative displacement was 299.7 mm in

only two days. The roll axis on the involved DMS module reached its saturation angle (tilt>20°): the further displacement is calculated with the interpolation of its pitch axis, still active.

In the following table each triggering event has been described in detail considering also rain, cumulative rain, snow events and temperature.

Table 1 Triggering event data.

	1st Event	2nd Event	3rd Event	4th Event	5th Event
Rainfall start	12/12/2008 0.00	01/03/2009 6.00	31/03/2009 6.00	16/04/2009 6.00	26/04/2009 3.00
Displacement start	16/12/2008 6.00	02/03/2009 20.00	01/04/2009 12.00	22/04/2009 0.00	27/04/2009 8.00
Rainfall type	Snow	Rain/snow	Rain	Rain	Rain
Snow at ground	Yes	Yes	Yes	No	No
Temperature rise	Yes	Yes	No	No	No
Concomitant factors	Snow melting 90 mm	Snow melting 120 mm	-	-	-
Rainfall [mm]	70	44	63	160	77.6
Rainfall duration [h]	84	96	30	138	29
Critical intensity [mm/h]	1.8	1.7	2.1	1.16	2.7
Total cumulative rainfall [mm]	190	354	480	590	800
Cumulative rainfall event [mm]	150	164	180	110	220
Total cumulative displacement [mm]	11.5	160.6	209.0	225.0	524.7
Cumulative displacement event [mm]	11.5	149.1	48.4	10.0	299.7

Improvements with respect to previous applications

Data, for the first time, were relating to the overall landslide body (both superficial landslide zone and deep creep zone) and water table at the same time in order to model the complex phenomenon. Thanks to a multiparametric approach it was possible in this way to deepen the knowledge of the geotechnical and kinematic model in a short time.

For each event was calculated moreover a particular value, the critical intensity, that correspond to the ratio between precipitation quantity (calculated in mm) that caused triggering movement and its duration (calculated in hours).

The interpolated line in the bi-logarithmic plot can be considered a site specific deterministic approach to the limit equilibrium threshold that separates the stability and instability field (Fig 6).

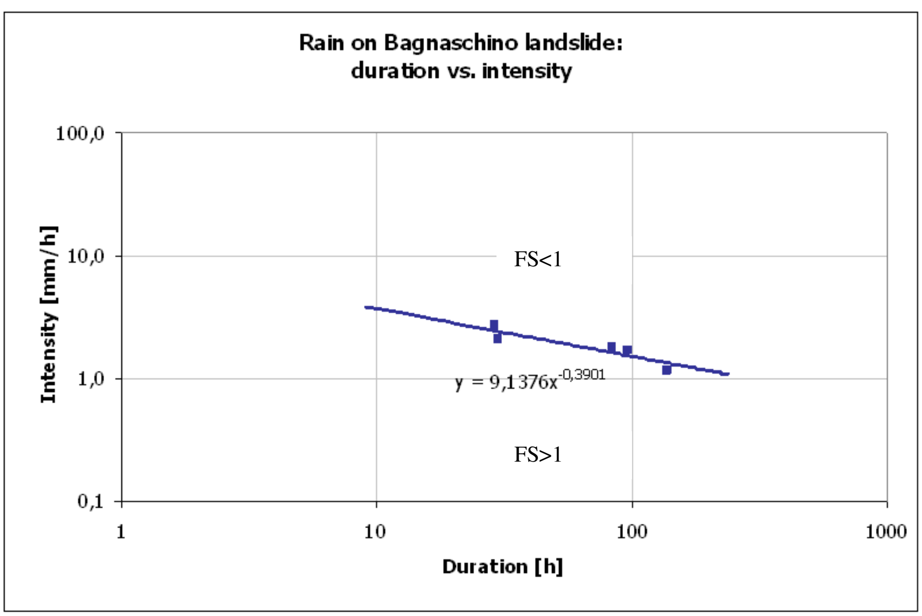

Figure 6 : Rain intensity-duration, Bagnaschino site

The site specific equation describing the rainfall thresholds for the initiation of the Bagnaschino landslide (rainfall, duration) can be written in the following way:

$$I = c + a * D^{-\beta}$$

Where in the specific site:
c= 0
a= 9.1376
β= 0.3901

The following diagram shows the site specific experimental equation elaborated by the DMS data, compared with the regional analysis available in literature basic on national and international cases (Fig 7).

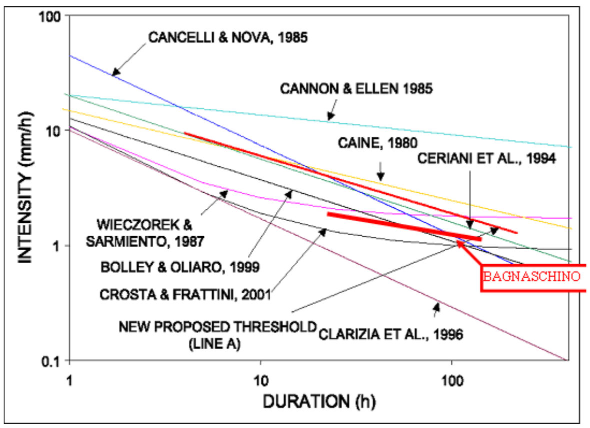

Figure 7 : Rain intensity-duration in literature

DMS column allowed obtaining with continuity the kinematics of the landslide in action, not only limited to the initial stages of trigger, but also during the evolution up to achievement of stasis conditions.

The integrity of DMS column is preserved in spite of the displacement recorded of 600 mm; this is a significant improvement, probably the largest deformation recorded at only one module (length =1m) considering also that the instrumentation was still active and operating correctly (Fig 8).


Figure 8 : Recovery of DMS column and displacement control

The excavation realized confirmed depth, direction and extent of the displacement, allowing the complete recovery of the instrumentation.

The activity in Bagnaschino with the cooperation of the Cuneo County allowed also repairing the inclinometer Al pipe that was replaced and protected by another pipe with a larger diameter in the interval of interest reaching the surface. This solution tested specifically in Bagnaschino will allow maintaining a long term monitoring both in the shallow zone and in the lower part of the landslide.

This experience was discussed inside the EU Safeland project 2009-2012 “Living with landslides risk in Europe: assessment, effects of global change and risk management strategies”, in which Bagnaschino is a test site, during the Vienna Meeting in 2010,.

Continuous monitoring of the landslide allowed noticing weak deep creep in the interval 30-44 m blg in addition to considerable shallow movements. The activation of deep movements is delayed in respect to shallow movements, with a well defined behaviour.

A DMS system has been installed permanently in June 2010 for Early Warning function by means of 2 columns (DMS 1-60 and DMS 2-10 active in the intervals depths 20-60m and 0-10m).

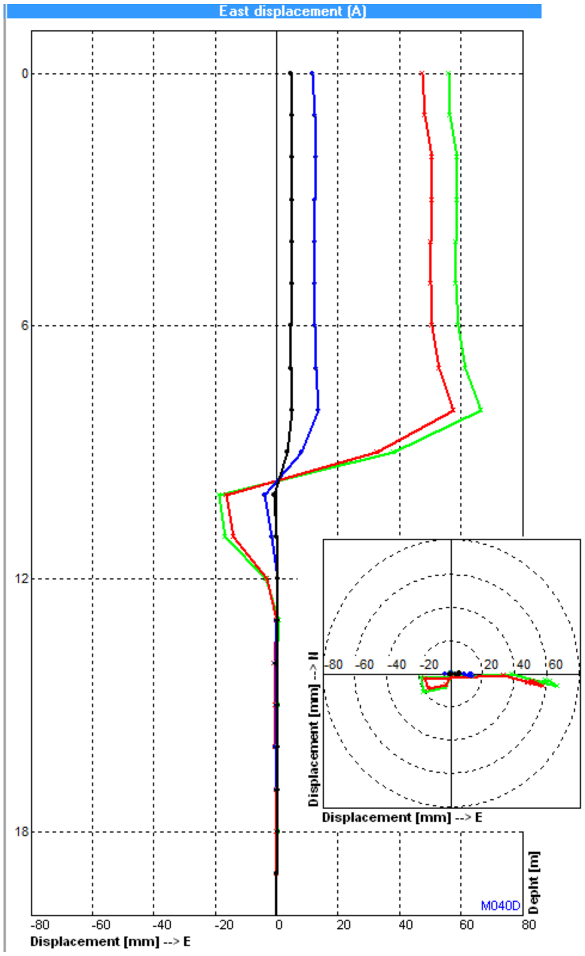

Figure 9 : Displacements in March 2011, cumulative East displacement and polar diagram

The integration of the real time monitoring data in risk management aspects.

The Province of Cuneo, using the available data from DMS system and taking into account the values of rain and the identified correlations between these parameters, manage aspects of civil protection related to the safety of the provincial road n° 164.. The remote data access and in real-time, supports the necessary management measures; in fact, on one side, the information in the system of Italian alert for the purposes of civil protection allows the activation of the procedures already being forecast, on the other side monitoring and processing of data of rain and displacement are the basis of decisions taken by the group responsible in order to possible necessary closure of the road. An example of these aspects may refer to the rain event that has affected the Piedmont Region in March 2011.

In fact a relevant triggering event occurs on site with starting the 12th of March since 8:00. At the beginning were recorded only micro-movements, but quickly grow up, reaching the 17/03/2011 a cumulative displacement of 63,3 mm at 8 mbgl. Figure 9 shows the displacements in the interval 15th-18th of March. The event monitored reached a level of stasis and the cinematic stopped on the 21st of March, lasting a total of 9 days for an overall displacement of 71,5 mm.

On the basis of the analysis of these information Province of Cuneo, already in the level of enhanced alert as a result of the forecasts of Meteorological Bulletins, has ordered the closure of the road no. 164 on the day 13 /03/2011 with reopening the day 21 /03/2011 .

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