Bagnaschino Landslide: From Early Warning to Site-Specific Kinematic Analysis

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During the flood event in 1994, the highway no. 194 was seriously damaged by a composite landslide activated in Bagnaschino (Torre Mondovì, Cuneo). In proximity of km 1400 the landslide invaded the carriage way. The estimated area and volume involved are 150,000 m^2 and 1.2 million m^3, respectively.

In order to continuously monitor the stability conditions, the Province of Cuneo (Civil Protection Office) established a slope monitoring plan in 2008 with a DMS column 60 m long. The instrumentation was installed for a monitoring stage in a borehole (28th October 2008 – 13th July 2009) connected to a local control unit and equipped with solar cell power supply and GSM data transmission.

DMS is a multiparametric system for the stability monitoring of slopes, excavation fronts, engineering works; the column is like a spiral cord composed of a sequence of hard tubular modules connected to each other by special flexible 2D-3D junctions that mimic any deformation, working continuously for Early Warning functions.

Fig 1, 2: DMS column installation (28th October 2008) and removal (13thJuly 2009) – Bagnaschino site.

Correlation between DMS column and weather 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 continuously monitor different kinematics and different weather conditions. The DMS column allowed investigating 5 triggering events and their relative period of stasis, with a clear delay time after rain events or snow melting.

The following describes the characteristics of each event:

- ***First event:*** 28th November, 2008, saw 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. At the same time, 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 light rainfall followed 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 began.
- ***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, which 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 diagram and table each triggering event has been described in detail considering also rain, cumulative rain, snow events and temperature.

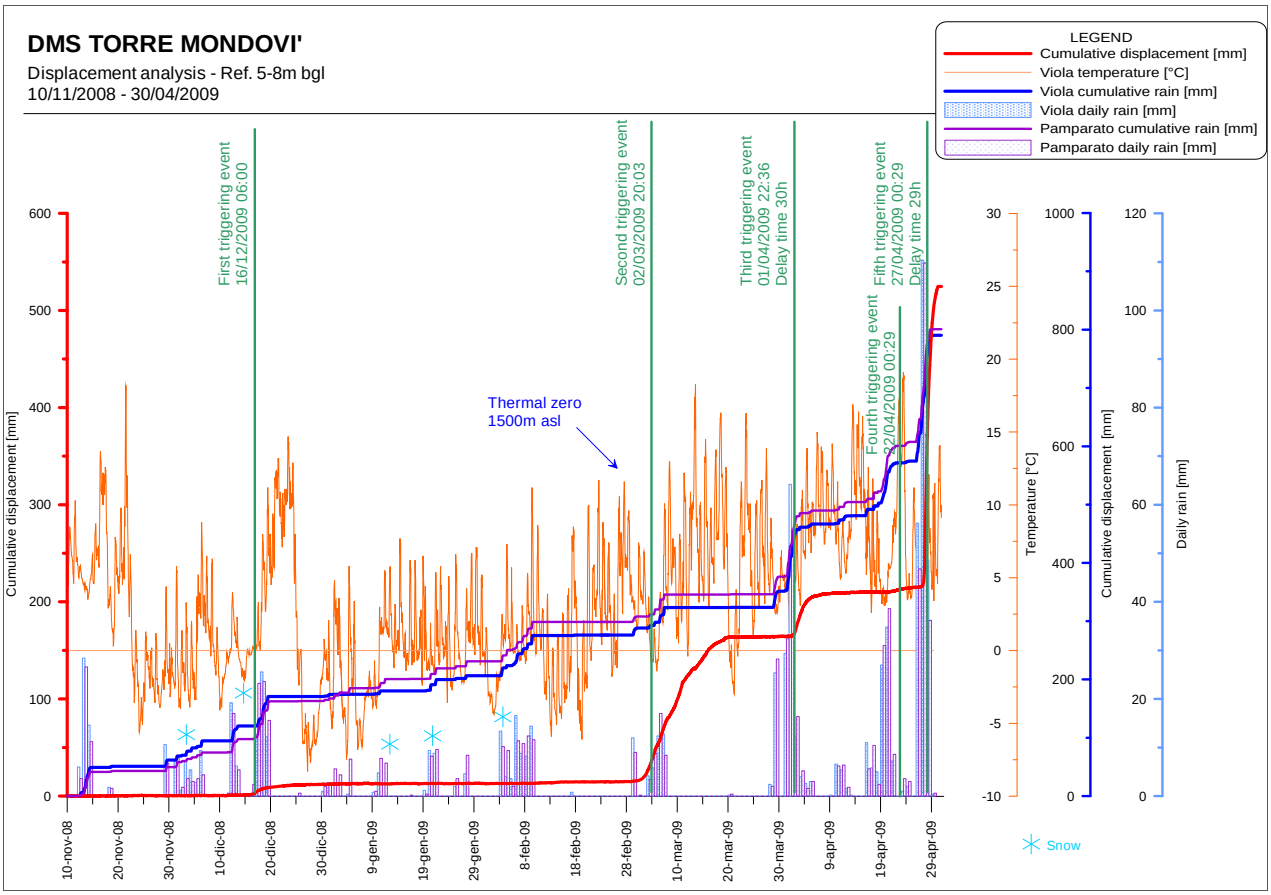

Fig. 3: Triggering events.

Table 1: Triggering events.

	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]	1.786	1.708	2.100	1.159	2.676
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

For each event a particular value was calculated, the *critical intensity*, that corresponds 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.

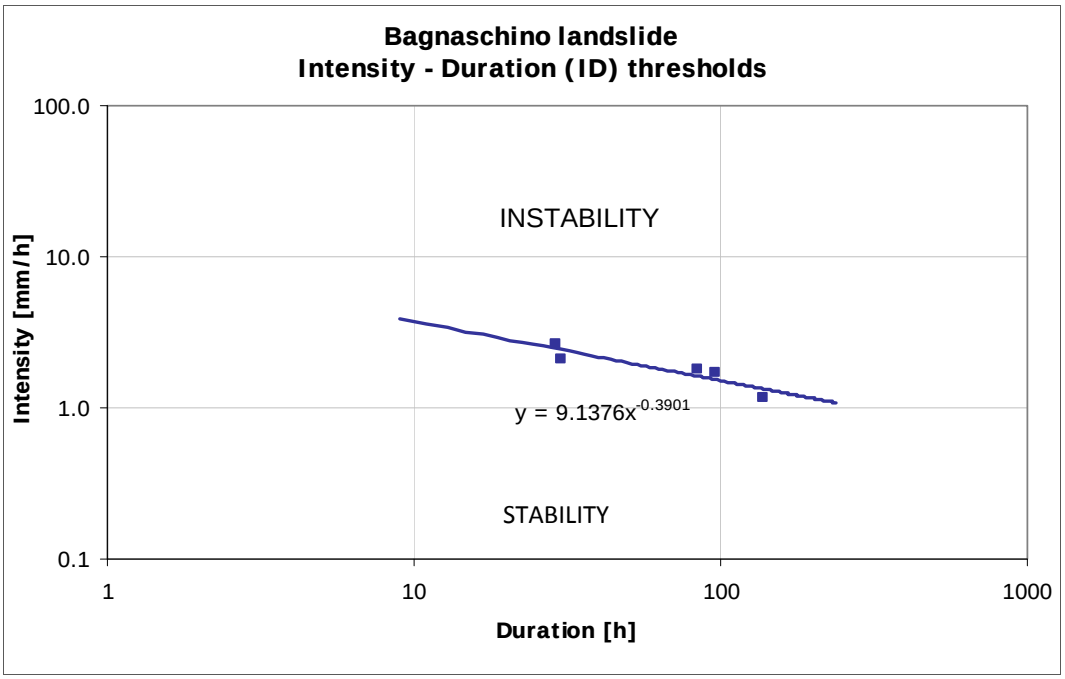

Fig 4: Rain Intensity – duration, Bagnaschino site.

On 13th July, 2009, the DMS column was removed (Figure 2). The DMS column allowed to obtain with continuity the kinematics of the landslide in action, not only limited to the initial stages of triggering, but also during the evolution up to achievement of stasis conditions.

The integrity of the DMS column is preserved in spite of the displacement of 60 cm; the excavation realized subsequently to release the column confirmed depth, direction and extent of the displacement, allowing the complete recovery of the instrumentation and the repair of the inclinometric pipe that is replaced and protected by another pipe with a large diameter.

Continuous monitoring of the landslide allowed to notice 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 well defined behaviour.

A new DMS system will be installed in spring 2010 for Early Warning function by means of 2 columns (DMS 1-60 and DMS 2-10 active in the intervals depths 20–60 m and 0–10 m). The Bagnaschino landslide is a test site within the EU SafeLand project 2009–2012.