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Emergency management of landslide risk during Autumn-Winter 2008/2009 in Calabria (Italy). The example of San Benedetto Ullano

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Abstract: The rains fallen in the last Autumn-Winter seasons, abundant and prolonged over wide sectors of Southern Italy, confirmed the overall fragility of the territory by triggering a great number of slope movements and erosive processes, floods along numerous streams, inundation of cultivated fields and of urbanised sectors, and coastal instabilities induced by sea-storms.

In Calabria, located at the southernmost tip of the boot, the recent geo-hydrological crisis was so severe that the Italian Government had to declare the "state of emergency" on 30 January 2009. The inheritance of the Autumn-Winter 2008/2009 extends over large portions of the territory. Among the examined cases, those characterized by conditions of "imminent danger" to public safety resulted mainly located in the NW sector of the region, along the Eastern slope of the Coastal Chain, and subordinately along its Western slope facing the Tyrrhenian Sea. Other villages were also threatened by slope instabilities along the Southern Tyrrhenian and on the Jonian coasts.

In the present study, the progressive mobilization of a rainfall-induced slope movement threatening the Southern suburbs of San Benedetto Ullano (Cosenza), activated on 28 January (and still active in early April), is briefly described. The results of a detailed geomorphologic field survey, repeated in time to properly recognising the evolution of the phenomenon, combined with the cross-analysis of rainfall data and superficial displacements at a number of datum points, allowed to support the Major of the village for better managing the state of geo-hydrological emergency.

The assessment of the scenarios related to the presumable development of the phenomenon is in progress. The simplified control system, promptly implemented during the first phases of analysis, will be refined in the next months, based on geological and kinematic data which will be progressively gathered via explorative drillings and thanks to the installation of essential instrumentations. Accordingly, even the set of provisional emergency procedures devised from the very beginning of the study will be detailed and may be arranged into a refined Decision Support System; advices for slope remediation will also be given to the local administration.

Keywords: *Rainfall-induced landslide, Risk management, State of emergency, Decision Support System (DSS), Calabria*

1. INTRODUCTION

Italy has the highest number of deaths or missing people, and the highest expected yearly losses of life in Europe due to slope instabilities; after Japan, the Country also boasts of its highest risk among the industrialized countries (Guzzetti, 2000). The rains fallen in the last Autumn-Winter seasons, abundant and prolonged over wide sectors of Southern Italy, confirmed the overall fragility of the territory by triggering a great number of slope movements and erosive processes, floods along numerous streams, inundation of cultivated fields and of urbanised sectors, and coastal instabilities induced by sea-storms.

In Calabria, located at the southernmost tip of the boot, the recent geo-hydrological crisis was so severe that the Italian Government had to declare the "state of emergency" on 30 January 2009. By the middle of January, thousands of superficial landslides had already affected the territory, causing severe damage to life lines, roads, urbanised areas and lands. Unfortunately, two victims had also to be recorded as a consequence of a landslide triggered at the 283 km of the highway "A3 Salerno–Reggio Calabria" on 25 January. Abundant rains kept on falling in the following weeks until the end of March, thus progressively activating even deeper phenomena along the slopes.

At the beginning of Spring, only thanks to fortuitous circumstances, the triggered phenomena had not taken an even heavier toll of lives (cf. e.g. the case of the mudflows triggered at Tropea). Tens of sections of the provincial roads in the Cosenza province (in the northern portion of the region, the most affected by the effects of the recent rains) resulted still interrupted, and several villages were facing the problems of sheltering the evacuees, and of repairing the main roads and infrastructures.

The inheritance of the Autumn-Winter 2008/2009 extends over large portions of the territory. Major effects were recorded in the sites shown in Figure 1. Under the co-ordination of the National High Risks Committee, they were examined by a team of experts recruited to form a Scientific Evaluation Group, with the task of supporting the Crisis Unit instituted by the Prefect of Cosenza on February 1st (Versace, 2009).

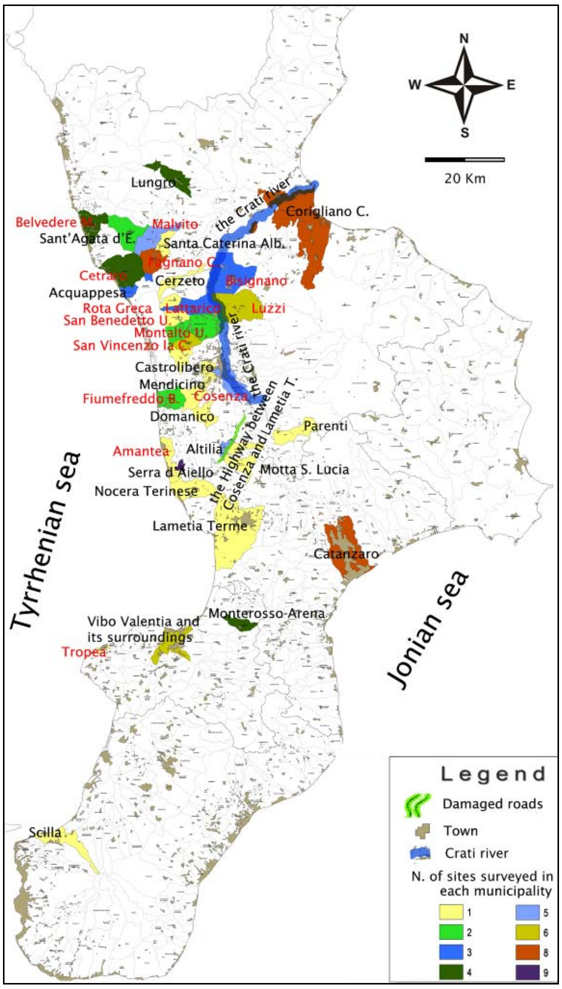


Figure 1. Municipalities examined by the Scientific Evaluation Group (after Versace, 2009, mod.). The number of sites surveyed is shown by different colours (cf. legend). In red, the names of the villages with the worst risk conditions.

Experts were selected from the local University and the CNR-IRPI, from the regional Basin Authority and the Department of Public Works, and from the Fire Brigades. Among the examined cases, those characterized by the worst conditions of "imminent danger" to public safety resulted mainly located in the NW sector of the region, along the Eastern slope of the Coastal Chain, and subordinately along its Western slope facing the Tyrrhenian Sea. Other villages were also threatened by slope instabilities along the Southern Tyrrhenian and on the Jonian coasts. Few examples of the main types of effects induced by the rains are shown in Figure 2.

In the present study, the progressive mobilization of a rainfall-induced landslide threatening the southern suburbs of San Benedetto Ullano (SBU), Cosenza, is described. The results of a detailed geomorphologic field survey, repeated in time to properly recognising the evolution of the phenomenon, combined with the cross-analysis of rainfall data and superficial displacements, allowed to support the Major of the village for better managing the geo-hydrological emergency. The assessment of the scenario related to the presumable development of the phenomenon is in progress. The simplified "empirical" control system, promptly implemented during the first phases of analysis, will be refined in the next months, based on geological and kinematic data which will be progressively gathered via explorative drillings and thanks to the installation of essential instrumentations. Accordingly, the set of provisional emergency procedures devised from the very beginning of the study will be detailed and may be arranged into a refined Decision Support System (DSS).

Figure 2. Some effects of the Autumn-Winter 2008/2009 in Calabria. a) top-left: soil slips affecting buildings at Cetraro (CS). b) top-centre: earth-fall threatening a building at Petilia Policastro (KR). c) top-right: large earth slide affecting the provincial road at Piano dei Rossi – San Benedetto Ullano (CS); d) bottom left (courtesy of: Maurizio Giglio – Emmegi Arts): the eastern portion of the Cemetery of Fagnano Castello, destroyed by a rotational slide. As a whole, most of the induced landslides were superficial (of either rock/earth fall or earth slide types) which affected many roads and the railway networks, the lifelines and lots of cultivated fields.

2. THE STUDY AREA

The Calabrian Arc (CA - Amodio-Morelli et al., 1976) is an accretionary wedge made of a series of Jurassic to Early Cretaceous ophiolite-bearing tectonic units (Liguride Complex), plus overlying Hercynian and pre-Hercynian basement nappes (Calabride Complex). In Oligocene-Early Miocene, these units were emplaced with NE-vergence on the Mesozoic sedimentary and metasedimentary terranes of the Apennine Chain.

Since Middle Miocene, overthrusting and the progressive migration of the CA towards southeast combined with the opening of the Tyrrhenian basin. In Late Pliocene-Early Quaternary, the CA was dissected by normal faults and fragmented into structural highs and marine basins. Since Middle Pleistocene, an intense WNW-ESE oriented regional extensional phase occurred, resulting in the "Calabrian-Sicilian rift-zone" (CSrz - Monaco and Tortorici, 2000 - Figure 3), a normal fault belt running along the eastern coast of Sicily and the western side of the CA. The development of the CSrz coupled with a strong regional uplifting of the whole CA. For the central and north portions of the CA, an innovative interpretation of the tectonic framework, dominated by strike-slip tectonics lasting from Late Miocene to Quaternary, has recently been documented by Tansi et al. (2007).

San Benedetto Ullano (450 m a.s.l.) is located in Northern Calabria, along the left flank of the Crati Graben (cf. Figure 3). It lies at the base of the Coastal Chain, in a sector marked by a N-S trending normal fault (belonging to the above mentioned CSrz), which extends for ca. 30 km from S. Fili to S. Marco Argentano. Along such fault, the metamorphic rocks of the Coastal Chain, to the West, give place to the Pliocene-Quaternary sediments of the Crati Graben, to the East.

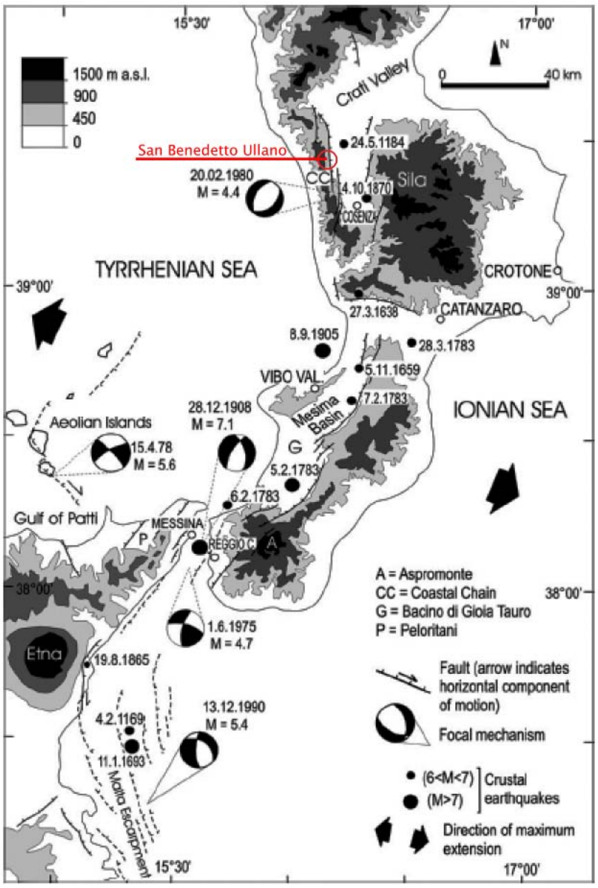


Figure 3. The Calabrian-Sicilian rift-zone, and major crustal earthquakes (depth < 35 km) since 1000 A.D. (after Tansi et al., 2007).

In Calabria, average yearly rainfalls vary between 1000 and 2000 mm/y in mountainous and internal areas, and between 600 and 900 mm/y in coastal areas, with a mean regional value of about 1150 mm/y. As also confirmed in a recent review of the general frame of storm conditions in Calabria, heavy rains are by far more frequent on the Jonian side of the region (Terranova, 2004). Over 70% of the yearly precipitation occurs from October to March, with negligible monthly values from June to September.

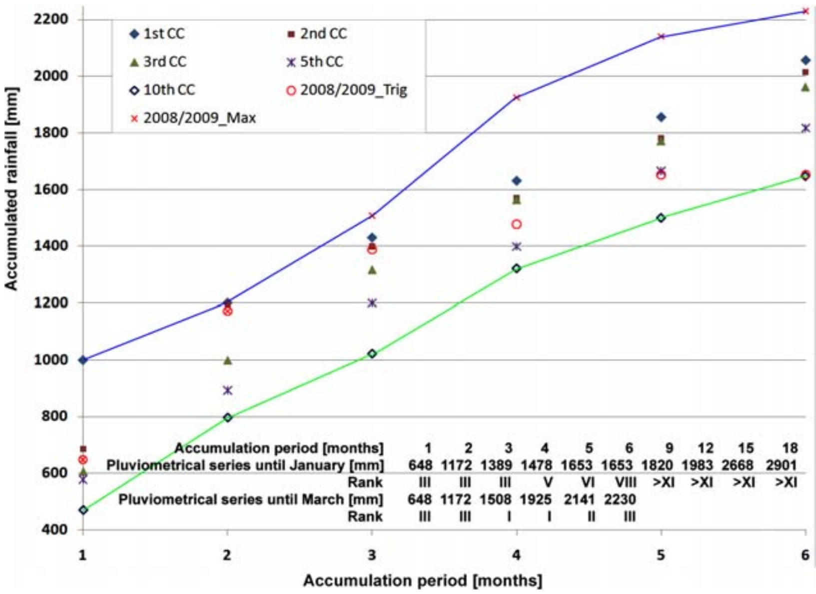
As concerns the surroundings of San Benedetto Ullano, yearly rainfalls are mainly related to prevailing western storms coming from the Tyrrhenian Sea, and reach the highest observed values in Northern Calabria (Versace et al., 1989). Average monthly rains recorded at Montalto Uffugo (i.e. the closest gauge) are shown in Table 1. The mean annual rainfall at the same rain gauge is about 1334 mm.

Table 1. Montalto U. rain gauge (468 m a.s.l., about 4 km SE of SBU). First row: monthly averages (in mm) computed for the period 1921-2006; second row: values (in mm) of the Autumn-Winter 2008/2009.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	198.1	160.3	132.8	98.9	64.6	27.8	18.3	28.6	70.4	125.1	187.9	220.8
2008/2009	647.8	335.6	417.0	-	-	-	-	-	174.8	89.0	216.6	524.4

3. AUTUMN-WINTER 2008/2009 RAINS AND LANDSLIDE ACTVATION AT SBU

During Autumn-Winter 2008/2009, Calabria - especially its provinces of Cosenza and Reggio di Calabria - was affected by severe storms. Most of the rains fallen from December to January; though, the main rainstorms occurred since November, and continued until the end of March with unusual frequency. At the gauges of Montalto U. and Fagnano Castello (516 m a.s.l., ca. 17 km NW of SBU), on the inner side of the Coastal Chain, cumulated amounts from November to March exceeded more than twice the seasonal average. In San Sosti (350 m a.s.l., ca. 28 km NW of SBU), the rainfall in the same period exceeded by more than 1.6 the historical average.

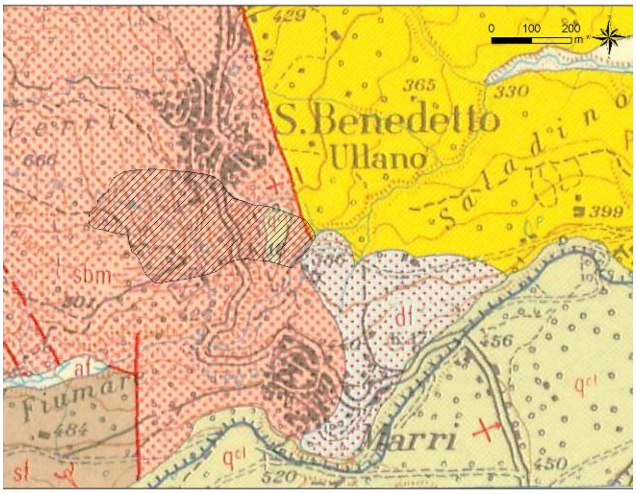


For a better understanding of the effects of the recent rainstorms, those occurred in January-March should be added to the rains, also significant, which fell in November and December (Table 1); the value of September, notable in itself, can instead be ignored, thanks to the low value of October. During the 2 and 3-months antecedent to the landslide mobilization, cumulated rains are very close to the first two critical cases ever recorded at the rain gauge of Montalto U. since 1921 (cf. Figure 4).

Figure 4. Cumulated monthly rains at Montalto U. for the Autumn-Winter 2008/2009 (red circles: until mobilization; red crosses: 2008/2009 maxima) and most severe historical cases (reference period: 1921-2006). Key: CC) critical case. In the table (at bottom), the maximum values of monthly cumulated rainfalls are ranked according to historical records.

The gravitational phenomenon developed along the Eastern slope of the Coastal Chain, skimming along the south margin of the village, and the north border of the cemetery, on its left and right flanks, respectively (Figures 5 and 6). It started mobilizing on 28 January, when a set of fissures was first noticed by the inhabitants along the local road network and the provincial road to the hamlet of Marri. Hence, the rainfalls relevant for the triggering of this slope movement fell between November 2008 and January 2009.

In the site affected by the recent instability, an inactive landslide is reported in the landslide risk map of the regional Basin Authority (PAI, 2001); nevertheless, the area recently mobilized resulted by far larger than the mapped one. A tectonic unit made of migmatitic gneiss and biotitic schist crop out in the affected area; rocks are weathered at places and mantled by few meters of colluvium. In its upper part, the sector is crossed by branches of the Abatemarco water system (which serves tens of villages in the Cosenza province). In the middle part, a municipal road connects the village to a deconsecrated church (S. Rocco) and to the cemetery.



In the lower portion, the area is crossed by the provincial road to Marri; the building of the Perrotta family plus its annexes also lie in this zone. At the base of the relief, a break in slope coincides with a segment of the N-S San Fili-San Marco Argentano normal fault, and marks the transition to Early Pliocene deposits (clay with subordinately sand and silt).

In the first period of landslide activity, fissures mostly opened along the cited road network. On 31st January, the widths reached ca. 20 cm, indicating maximum superficial velocities of 7 cm/day in several sites; on 30 January, a peak of ca. 10 cm/day had been recorded along the municipal road, upslope of the S. Rocco church (cf. Figures 6 and 7).

Figure 5. Lithologic map of SBU (after CASMEZ, 1967). Key: sf) phyllite; sbm) migmatitic gneiss and biotitic schist; q^{cl}) conglomerate; df) landslide debris; af) alluvium; P^{a}_{1-2}) clay. The recent unsettled zone is hatched in black.

Starting from 5 February, fresh fractures were clearly recognised also in the cemetery, in the forest land, and downslope of Perrotta's building. At the middle of February (following a moderate snowfall), scarp segments 40 cm high and up to 30 m long developed in the uppermost sector of the slope, arranged in irregular portions and missing a clear unicity. In the following weeks, fractures kept on widening and lengthening, and new ruptures gradually opened even outside the sector affected by the first instability. As a consequence, location of datum points had to be progressively adjusted, based on the results of the geomorphological and kinematic surveys. The above-cited peak velocities of superficial displacement, recorded at the datum points during the first stages of activation, were never observed again in the following weeks (cf. Figure 7). Significant velocities (in the range 4-5.5 cm/day) were observed between 8 and 12 February, in coincidence of two days of intense rains (over 120 mm).

Repeated detailed geomorphologic field surveys - carried out every 24h in the first days, and then 2-3 times per week in the following two months - allowed to map the evolution of the phenomenon, and to progressively update the extent of the affected zone. In addition, a set of datum points had been selected over the landslide body and along its margins, to monitoring the kinematics of the phenomenon by means of recurrent hand-made measures of superficial displacement. Starting from 11 February, a set of precision-extensometers was also installed, and a real-time system (ADs) of data collection, transfer via GSM, and processing was implemented thanks to the support of a specialized Company (Advanced Devices S.p.A.).

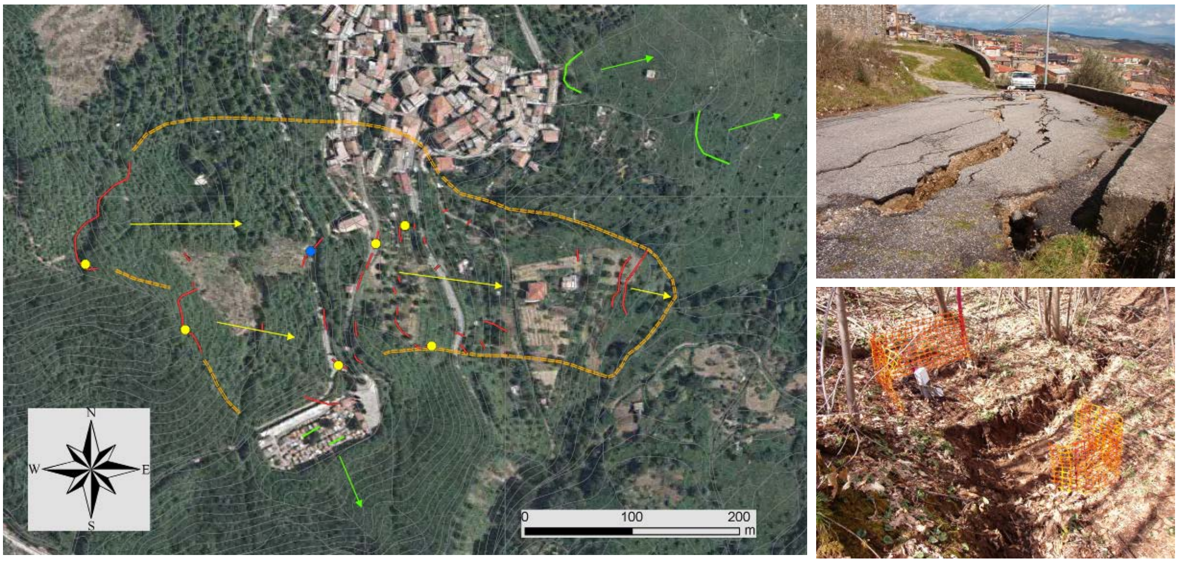


Figure 6. On the left, a map of the landslide area. Key: in red) observed fractures; yellow arrows) vectors of movement; in orange) assumed borders of the phenomenon; in green) fractures and vectors related to local phenomena; blue dot) datum point #1, upslope of the S. Rocco church; yellow dots) location of the extensometers. On the right, two of the instrumented sites: on top, the road to the church; on bottom, the upper scarp in the forest (pictures taken on 25 March).

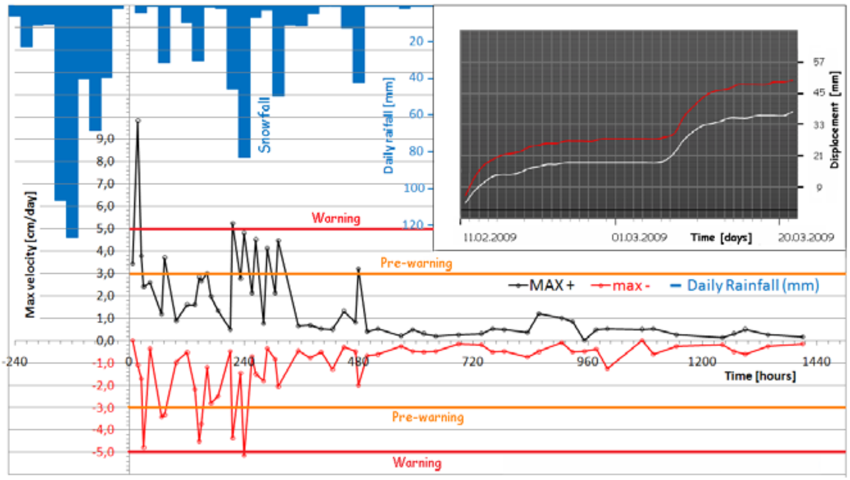


Figure 7. Daily rains at Montalto U. (blue bars, top-left), and daily velocity of superficial displacement (bottom), until the end of February and March, resp. Maximum daily values of extension (in black) and compression (in red) observed at the set of datum points are shown. The time axis starts from the beginning of the hand-made measurements of displacement (t_0 = 31 January). The antecedent rains are also shown for a period of 10 days.

In Figure 7, on top-right, an example of displacements monitored in real-time via the ADs is also shown, from 11 February to 20 March (data from the extensometers located by the church of S. Rocco, and by the cemetery, are drawn in red and in grey, resp.). The landslide activation was preceded by antecedent rainfalls exceeding 500 mm in the last 10 days. For the period considered, a clear relationship between rains and displacements comes out, with quasi-immediate responses (ca. 12-24 h) for rains exceeding 30 mm/day.

4. EMERGENCY RISK MANAGEMENT

Even though characterized by a quite complex behaviour, daily displacements resulted to be generally consistent among themselves, and showed a clear relationship with rains. Based on the spatial distribution of the fractures, on their attitude and dimension, and on kinematic observations, the surveyed features were interpreted as evidence of a confined unitary slope movement (comprising a smaller pre-existing landslide body), undergoing an incipient phase of activation. Given the proximity of some buildings on the left margin of the threatened area (cf. Figure 6), and taking into consideration the daily values of displacements and rains, the Major decided to adopt precautionary measures since the first phases of activation, by evacuating the inhabitants and interdicting the traffic along the local road network. The management of the emergency took advantage of the scientific support given by the staff of the CNR-IRPI, and of the real-time data-gathering system jointly implemented with the mentioned specialized Company, and provided timely advise on security procedures during all the phases of development of the phenomenon.

In absence of a detailed knowledge of the phenomenon, emergency basic procedures for risk mitigation were empirically devised by considering the thresholds for daily maximum punctual velocities (Table 2), recently adopted for a similar case study by Iovine et al. (2006). Values of superficial displacement and other evidence of evolution were obtained through systematic (hand-made) measurements, carried out along fissures and scarps by a team of technicians of the municipality and by volunteers. The set of datum points employed for the measurements consisted of 33 sites, distributed on the body of the landslide and along its borders; they were defined since the first phases of mobilization (31 January) and progressively adjusted in the following weeks, in accordance with the development of the phenomenon. Starting from 11 February, an additional set of automated extensometers (plus a meteoric station) was installed, to allow for high-frequency measurements and real-time data processing.

Table 2. Levels of alarm and adopted thresholds of maximum punctual velocity for urbanized areas (after Iovine et al., 2006, mod.). Values are expressed in cm/day. In the second column, the status names were revised, aiming at preserving – as far as possible - the original definition given by Tran vo Nhiem et al. (1988).

Level of alarm	Status of alarm	Maximum punctual velocity
0a	*normal*	$v < 0.75$
0b	*pre-alert*	$0.75 \leq v < 1.5$
1	*alert*	$1.5 \leq v < 3.0$
2	*pre-warning*	$3.0 \leq v < 5.0$
3	*warning*	$5.0 \leq v$

The adopted basic emergency procedures, empirically based on the values of measured superficial displacement and on other evidence of evolution, are summarized in Table 3. Daily rains were also considered for deciding on the transition between the levels of alarm.

As regards the automated ADs, it was implemented so that the frequency of measurements depended on observed values; accordingly, distinct automated protocols were defined to timely inform the team of experts of the CNR-IRPI and the Major of SBU.

Table 3. Suggested procedure of management of landslide-risk emergency at SBU. In Italics, instruments not available during the first phases of emergency (in some cases, they were available either later or outside the directly affected area).

Level of alarm	Summary of the suggested procedure
0a	Occasional patrol of the affected area, and measures at the superficial datum points, *inclinometers*, *piezometers*, *rain gauges*.
0b	Twice-monthly patrol of the affected area, and measures at the superficial datum points, *inclinometers*, *piezometers*, *rain gauges*.
1	Real-time monitoring via *ADs*; patrol of the affected area three times per week to recognize anomalous evidence of evolution; daily measure at the datum points, with immediate data transmission via e-mail; weekly patrol along the forest paths and the water system to recognize anomalous evidence; daily monitoring at *inclinometers*, *piezometers, rain gauges*.
2	Real-time monitoring via *ADs*; daily patrol of the affected area to recognize anomalous evidence of evolution; two daily measures at the datum points, with immediate data transmission via e-mail; three weekly patrol along the forest paths and the water system to recognize anomalous evidence; daily monitoring at *inclinometers*, *piezometers, rain gauges*. Pre-warning of inhabitants; closure of roads to traffic during night-time; night lighting of threatened streets and buildings.
3	Real-time monitoring via *ADs*; daily patrol of the affected area to recognize dangerous evidence of evolution; warning to inhabitants; evacuation of people from threatened buildings; closure of roads.

5. DISCUSSION

The simplified method of analysis adopted in the present study is based on detailed geomorphologic field survey, combined with the cross-analysis of hydrologic data and of superficial displacements. The choice of such an empirical approach of risk management was imposed by the need of prompt support to the Major during the first emergency phase. It should be stressed that the procedure summarized in Table 3 was defined to be performed by the technicians (and volunteers) of the municipality, after a short training period. It adds up to detailed surveying which had to be performed, with proper recurrence, by the experts of CNR-IRPI. As concerns the requirement of persistency in a given status of alarm, it was generally assumed that no measure or evidence exceeded the criteria for the specific level, and no other (e.g. meteoric, seismic) unusual condition was occurring. In case of single anomalous evidence, an immediate patrol at prefixed critical points had to be activated to verify in situ the actual conditions of the phenomenon; in case direct observations confirmed the suspicion of anomalous/dangerous conditions, an immediate survey of the CNR-IRPI experts had to be requested. On the other hand, in case several values of superficial displacement reached worrying amounts - better if related to distinct sectors of the phenomenon - or for a combination of worrying conditions for distinct parameters (e.g. groundwater level, daily and/or cumulated rains, deep displacements), the transition to the upper level was recommended.

Given the confined distribution of activity of the considered slope movement - which still showed minor evidence of activity in early April - a major effort was made to map the progressive development of the phenomenon, and therefore to properly select the locations for installing the instruments of the ADs. The superficial evidence related to the development of the main rupture surfaces migrated in time towards the flanks, downslope of Perrotta’s building, and far upslope in the forest land. In the considered case study, a further complexity was brought about by the presence of branches of the Abatemarco water system (serving more than 150000 inhabitants in the Cosenza province) which cross the sector affected by the landslide. On few occasions, breaks were noticed which coincided with short phases of acceleration of the landslide. Based on available information, a causal relationship between the breaks of the water system and observed accelerations can be suggested; moreover, the progressive deformation of the slope certainly caused the breaks observed after weeks of gravitational mobilization. Though, it is unknown if any “early” break may have contributed to the triggering of the slope movement.

In the near future, the above criteria will be refined by including other types of information derived from additional essential instruments (e.g. piezometers, inclinometers), and by applying suitable modelling techniques based on site-specific geotechnical and hydrogeological information. In fact, aiming at better monitoring the evolutionary trends of the phenomenon, a couple of explorative drillings are going to be carried out in the sector affected by the slope movement, and instrumented with a piezometer and an inclinometer; moreover, a rain gauge is going to be placed at a suitable location. All these instruments will be linked to the existing ADs, and data will be conveyed in real-time to the centre of data processing at CNR-IRPI. Thanks to such additional information, stability evaluations could be carried out by applying suitable modelling techniques, and the above cited protocols accordingly refined and arranged into a suitable Decision Support System, which may be integrated into the municipal Civil Protection Plan.

ACKNOWLEDGMENTS

The results of this study partly derive from an agreement signed by the Administration of San Benedetto Ullano (Major: Mr. Gianni Carnevale) and the CNR-IRPI, aimed at studying "...the triggering and evolutionary conditions of the San Benedetto Ullano landslide". The implementation of the in situ monitoring system, and the real time data transfer toward a local server were realized by the AD – Advanced Devices S.p.A. of Rende. A demonstrative website (simplified for privacy reasons) of the system can be accessed at http://www.advanceddevices.net/sbu/pub

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