Surface movements of a landslide involving weathered and degraded rocks

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Abstract: Alarming signs of instability appeared on a natural slope during the winter of 1998-99 near a town in Southern Italy. This fact induced Authorities to close the national way that gives access to the town of Acri. This safety measure then caused many difficulties for the populations of a vast mountain area. Surveys and preliminary investigations highlighted the need to set up a monitoring system, directly supervising the site, in order to re-open the road with acceptable risks for the population. It was decided to test and verify, for survey and control purposes, the use of surveying equipment for monitoring the surface movements of the landslide area. The paper shows the information gained and it underlines the contribution of monitoring activities to manage emergencies and plan risk mitigation activities and hazard reduction measures.

1 INTRODUCTION

Alarming slope stability problems were noted at the end of 1998 and the beginning of 1999 at the entrance to the town of Acri (Calabria, Southern Italy), in the Serra di Buda region - on a stretch of hillside alongside National Road SS660 (Fig. 1).

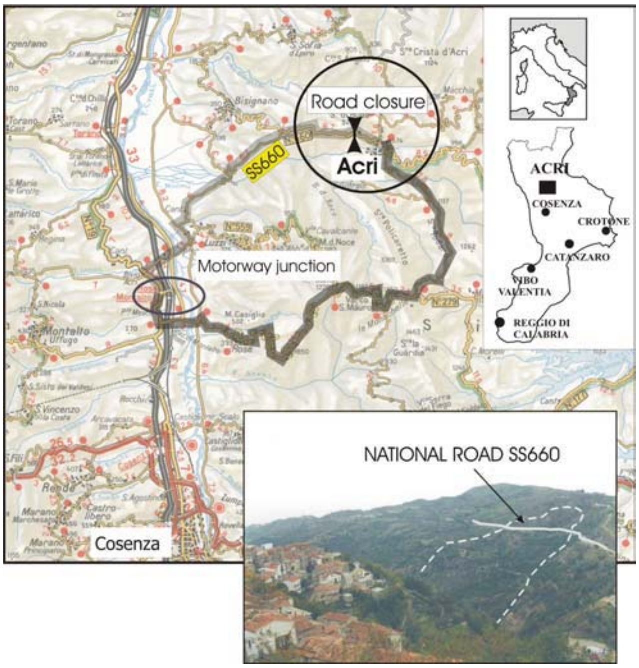

Fig. 1. Location of site and the landslide slope.

Fortunately, there were no important buildings in the area directly concerned by the slope instability (width varying from 100 m to more than 400 m, length approx. 500 m, difference in elevation between 250 m and 300 m). However, the effects recorded along SS660 road immediately aroused serious concerns. Since the very first sighting of the instability phenomenon (December 1998), it was expected, as later proved to be the case, that it would be necessary to close to traffic one of the main access roads to Acri, causing substantial hardships for an area to which access was already awkward.

The detailed surveys carried out after the remobilization in January-February 1999 enabled the recognition and marking of two active landslides (Fig. 2).

The first phenomenon, which covered approx. 11 ha and is the larger of the two, concerned the part of the hillside next to the town of Acri. The morphology of this first landslide is irregular. The main scarp, next to the ancient slope, starts at an elevation of 780 m a.s.l. and is about 100 m wide. Further down the slope the landslide cross-section spreads out until reaching a width of 450 m. The landslide near the SS660 road is approximately 200 m wide.

The morphology of the second landslide, which is smaller than the first one (approx. 2.5 ha), is more regular and has a long and narrow shape. The main scarp, which was probably guided by tectonic structures, has an irregular shape and reaches an elevation of 800 m a.s.l. It covers a footpath at a slightly lower level, at approx. 780 m a.s.l.. The lower part of this landslide also touches the SS660 road, over a distance of about 100 m.

The preliminary surveys and investigations carried out on the landslide, located in an area in which extremely weathered and degraded crystalline-metamorphic Palaeozoic lithotypes are present, enabled the setting up of a monitoring system, with direct surveillance of the site. This enabled the road to be reopened and reduced the access difficulties (Sorriso-Valvo *et al.,* 2001; Gullà *et al.,* 2001; Gullà *et al.,* 2002).

The situation which evolved lead to the decision to test and check, for surveying and control purposes, the use of motorized total station for the monitoring of the surface movements (Bonci *et al.,* 2002).

The collected data is analysed after describing the monitoring network and defining the implementation criteria. Some surveying information is given and useful comments for control monitoring are made.

Fig. 2. Limit of area concerned with 1998-1999 remobilization. Legend: 1= landslide crown; 2 = landslide limit; 3 = type of movement (sliding); 4 = debris deposits with large blocks; 5 = debris deposits. From Sorriso-Valvo *et al.* (2001).

2 SURVEY MONITORING NETWORK

The monitoring network for control of the surface movements was set up under emergency conditions, in an operational context which may be summarised as follows: slope instability characterised by still active movements; indefinable volume involved; materials not classified from a physical/mechanical point of view; cause of landslide not clearly defined; need to guarantee transit along the road effected by the instability with an acceptable level of risk. At the end of the first study phase referred to in this paper, it was seen that there was a good degree of efficiency of the instrumentation and the survey procedure used (Bonci *et al.,* 2002).

The survey monitoring network, which was operational from the end of October 1999, was initially formed by 9 monitoring benchmarks. Fig. 3 shows the final configuration of the network: 9 measurement points, located in the area of the landslide and in the immediate vicinity; 4 reference points, located in stable areas; topographical instrument and computer, located in a protected structure (Acri's ancient tower) with a good visibility of the landslide slope.

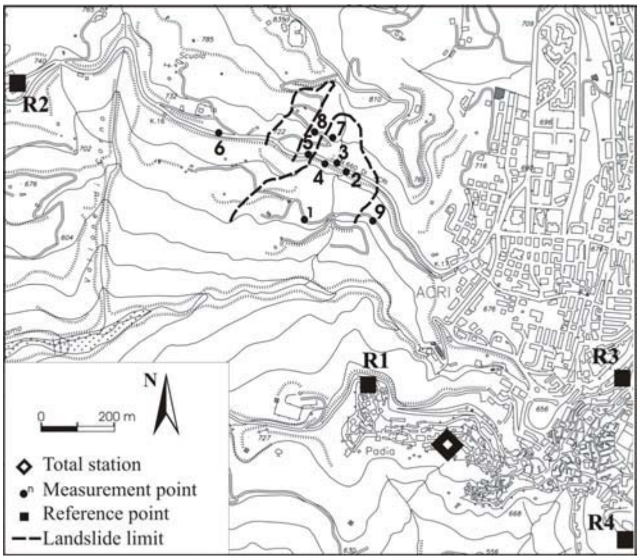

Fig. 3. Configuration of network for monitoring surface movements.

The location of the measurement points was decided upon in order to have the highest level of monitoring near to the SS660 road (points 2, 3, 4, 5 and 6), at the same time guaranteeing adequate information in the upper portion of the landslide (points 7 and 8) and below the road (points 1 and 9). Figure 3 shows that some points were located close to the morphological limit of the remobilization (points 5 and 8) and others in areas in which there should either be limited movements or none at all (points 6 and 9).

The exact locations of the measurement points were optimised by considering: visibility from the observation point, dynamic significance deduced from a preliminary geological model, position with respect to the SS660 road, distance from the observation point and accessibility. The poor visibility and difficult access prevented control of the slope close to the Calamo Stream with the use of instrumentation. The benchmark monuments have been set up in consideration of the specific characteristics of their installation site (concrete walls, retaining walls, ground cover, outcropping rock, etc.) (Bonci *et al.,* 2002).

After an initial data collection period, during which information on the development of the slope after the landslide event was obtained, the network was integrated with reference points located in sufficiently stable areas; a good layout of the network was achieved compatibly with problems of a logistic nature. Sites were identified which had, at the most, small movements with respect to those expected at the measurement points.

The total station was housed in a specially designed and constructed protective structure (Fig. 4c) located on Acri's municipal tower. The same building housed the computer for management of the topographical instrument and for the collection, processing and transferring of data, upon request, to two remote stations by GSM modem (Fig. 4). The location of the observation point was found to be the only one compatible with other requirements, such as adequate stability of the site, the necessary protection from intrusion and visibility of the landslide area (Fig. 3).

The measurements were initially taken at hourly intervals. After the installation of the reference points they were taken every 6 hours. The reference points, which constitute the reference datum, were surveyed first, followed by the measurement points. The data was automatically processed at the end of cycle, ready for transmission.

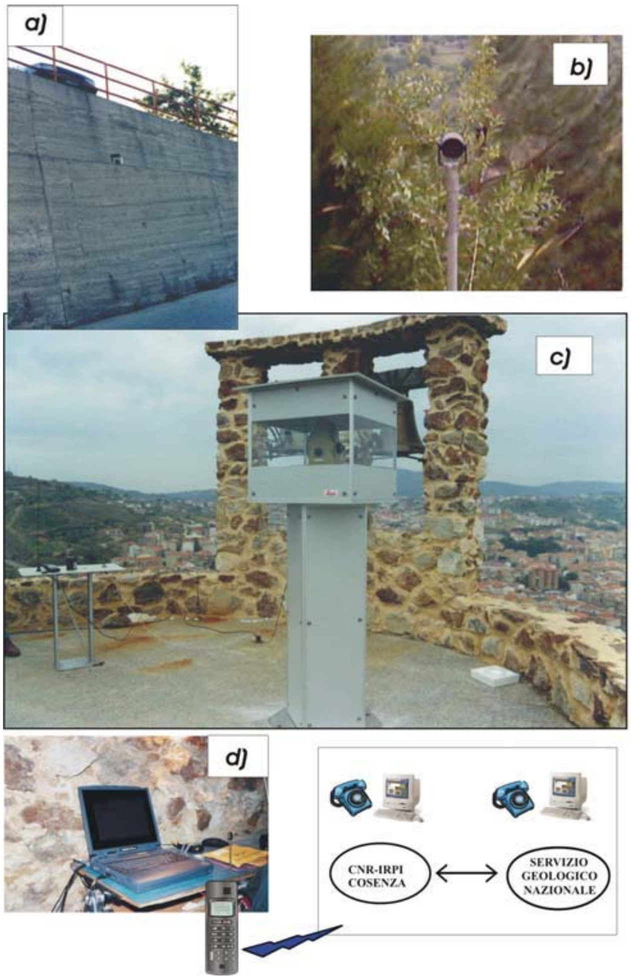

Fig. 4. Elements of the surface movement monitoring network: a) reference point, b) measurement point, c) total station, d) computer.

3 ANALYSIS OF SURFACE MOVEMENT MEASUREMENTS

Surface movement measurements taken with the total station are available from the end of October 1999 to the beginning of July 2002 (Bonci *et al.,* 2002).

The control of the movements during the first phase of monitoring was carried out considering variations in the direct distance between the observation point and measurement points.

After a careful study of the data following the installation of the reference points, the previous measurements were corrected by eliminating the rotations suffered by the total station. Moreover, in order to give continuity to the processing of the data during the July-October 2000 interruption, it was assumed that the movements during that period were the same as those for the following year.

The overall processing of the data provides the trend of the three movement components of the measurement points for the entire observation period. The movement components are referred to North, East and Elevation and are calculated as the average of the measurements collected during the day. Figure 5, in particular, shows the trend of the planimetric and altimetric components.

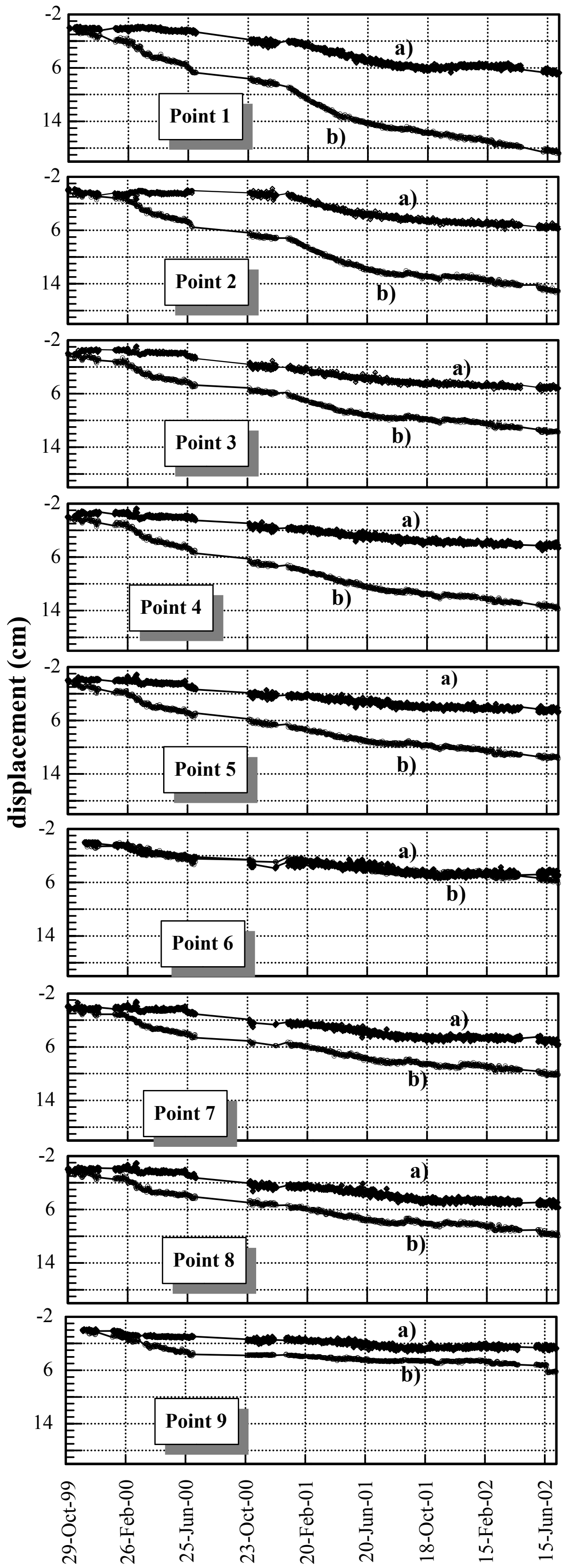

Fig. 5. Trend of the altimetric (a) and planimetric (b) components of the movements surveyed at the measurement points.

It may be seen that the movements accrued over the entire measurement period vary between approx. 3 cm and approx. 7 cm for the altimetric component, points 9 and 1, and they fall between approx. 19 cm and approx. 6 cm for the planimetric component, points 1 and 6. A detailed study of the data indicates that, considering the entire period, the error ellipse of the altimetric component (between 0.33 cm and 0.54 cm) is approximately twice that of the planimetric component in the North direction (between 0.16 cm and 0.32 cm). Even though both components are significant, it is believed that attention should be focussed on the planimetric component which is much more consistent.

An estimate of the planimetric movements for measurement point 2 during the period April 1999-July 2002, obtained by also considering the data provided by the GPS measurements carried out from April to October 1999 by Sorriso-Valvo *et al.* (2001), gives a value of about 50 cm.

Confirmation of the importance of the planimetric measurements is provided by the orientation of the vectors of the planimetric movement (Fig. 6). The angle with respect to North for all the measurement points varies from approx. 8° to 360°, but for the majority of the points (1, 2, 3, 4, 5, 7 and 8) the direction falls more frequently within the range of 183°-218° (96% for point 1, 75% for point 7).

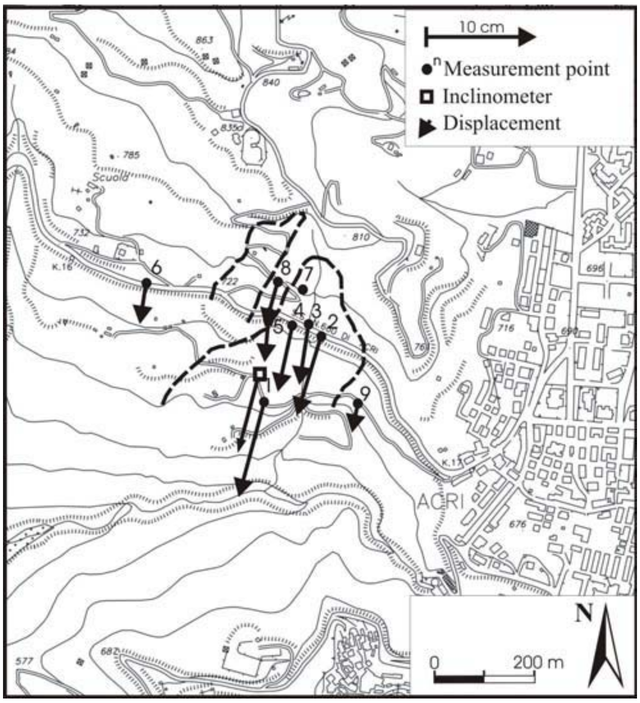

Fig. 6. Movements accrued between 12/1/01 and 8/7/02 and measurement of the movement at 1 m above ground level along the vertical line of inclinometer S3 during the same period of time.

For the points within or close to the area interested by the remobilization during the 1998-99 winter, the direction of the planimetric movements is contained within a 36° cone, the orientation of which is substantially parallel to section D-D' in Figure 6. Similar indications, in terms of both direction and module, are provided by the inclinometer measurements (Fig. 6).

Further details regarding the dynamic characteristics of the Serra di Buda landslide may be deduced from an analysis of the movement trends shown in Figure 5. These trends are substantially ascribable to various periods of time characterised by constant speeds.

The planimetric movements, even though they are different in terms of accrued modules, are similar, especially for points 1, 2, 3, 4, 5, 7 and 8 (curve b in Fig. 5). The altimetric movements, which differ less in accrued modules (all falling between 5 cm and 7 cm with the exception of point 9), also have similar trends and may be referred to a limited number of stretches characterised by a constant speed (curve (a) in Fig. 5).

A general study of Figure 5 with regard to the planimetric movements shows more acceleration and deceleration sequences: the average speed of the planimetric movements over the entire observation period and for all the measurement points varies from 0.019 to 0.006 cm/day; for the altimetric movements the average values are between 0.007 and 0.003 cm/day; there are also periods during which the speeds seem to be practically zero (e.g. in August 2001).

The speed of the movements in a vertical direction is very low (approx. 0.003 cm/day) and tends to zero during the final part of the observation period covered in this paper. The variations in speed do not appear to be related to the piezometric levels measured which, indeed, do not show particularly significant changes (Gullà *et al.,* 2002).

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If we consider the planimetric movements, and refer to measurement point 1, we can define eight periods, of 18 days over approximately one year, during which it may be seen that the speed of the measurement points lies in two intervals of from 0.01 to 0.02 cm/day and from 0.02 to 0.07 cm/day (Fig. 7). For the last period, from 5 August 2001 to 8 July 2002, there is still a speed of about 0.01 cm/day which at the start of the period in question seems to be tending towards zero as shown in Figure 7.

The highest speed, measured by the terrestrial monitoring network, is for measurement point 1 with approx. 0.07 cm/day, for 29 days (6 March-4 April 2000); for the same point there is a period of 94 days (14 January-19 April 2001) with a speed of approx. 0.05 cm/day; GPS measurements by Sorriso-Valvo *et al.* (2001) give a speed of about 0.45 cm/day for a period of 40 days (1 April-10 May 1999).

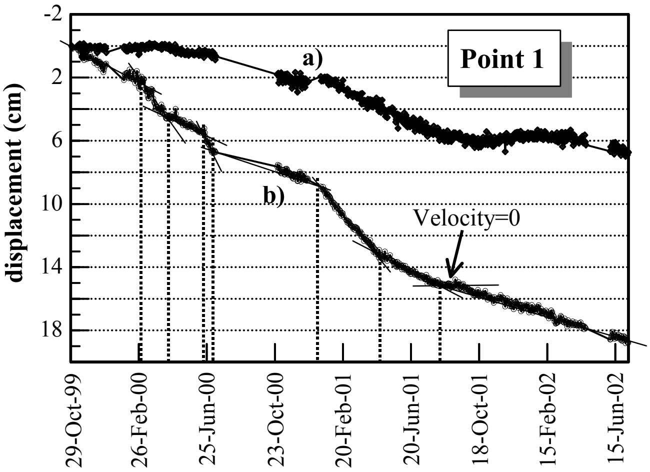

Fig. 7. Trend of the altimetric (a) and planimetric (b) components of the movements measured at point 1, and details of the periods in which the speed remains constant.

4 CONCLUSIONS

The study of the measurements of the surface movements carried out in this paper show that, even during emergency conditions, it is possible to design and implement monitoring networks which, as well as immediately providing important data for emergency control, can be quickly integrated for surveying and routine control of the slope stability.

The range of movements is homogeneous in terms of direction and modulo of the vectors. The data examined indicates that the landslide which occurred during the winter of 1998-99 is a translational slide and that the influence of the instability affects a larger area than that highlighted on a morphological basis (points 6 and 9, Fig. 6).

The post-failure phase, with a total movement at July 2002 of not less than 50 cm, has still not finished and the estimated speed between August 2001 and July 2002 is approximately 0.01 cm/day. The speed of the planimetric movements during some of the monitoring phases reached values of 0.07 and 0.05 cm/day, for 29 and 94 days respectively, and the movement for the entire period may be classified as very slow or extremely slow (Cruden & Varnes, 1996).

The general conditions of the slope suggest that it is necessary to continue the monitoring which, as far as the defined situation is concerned, may also be used for control purposes by initially paying careful attention to the movement speed values.

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