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Slope instability and the road-railway system in the Basento river valley (Southern Italy)

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ABSTRACT

Slope instability phenomena are widespread in the geological context of Southern Apennines. The paper reports the slope instability features characterized the medium valley of the Basento River, which is crossed by a major road/railroad stretch linking Potenza to Metaponto and which is not infrequently affected by instability phenomena. The attention is focused on one of the most significant landslides periodically reactivated by rainfalls which badly damaged the important railway line.

1 INTRODUCTION

Proneness to landsliding is a distinguishing feature of the Lucanian Apennine geomorphology and affects most of outcropping geological formations in the area.

Over the past decades, diffuse and massive landslides have repeatedly hit the region (Basilicata) and caused severe damage to urban centres, road and railway facilities and major civil engineering works following rainfalls which were not necessarily heavy. This paper describes slope instability conditions in a wide area in the middle valley of the Basento River (Basilicata, Southern Italy) and the relationships between the activation of landslides and the failures occurred along the Potenza - Metaponto railway line and some major connecting roads (Figure 1).

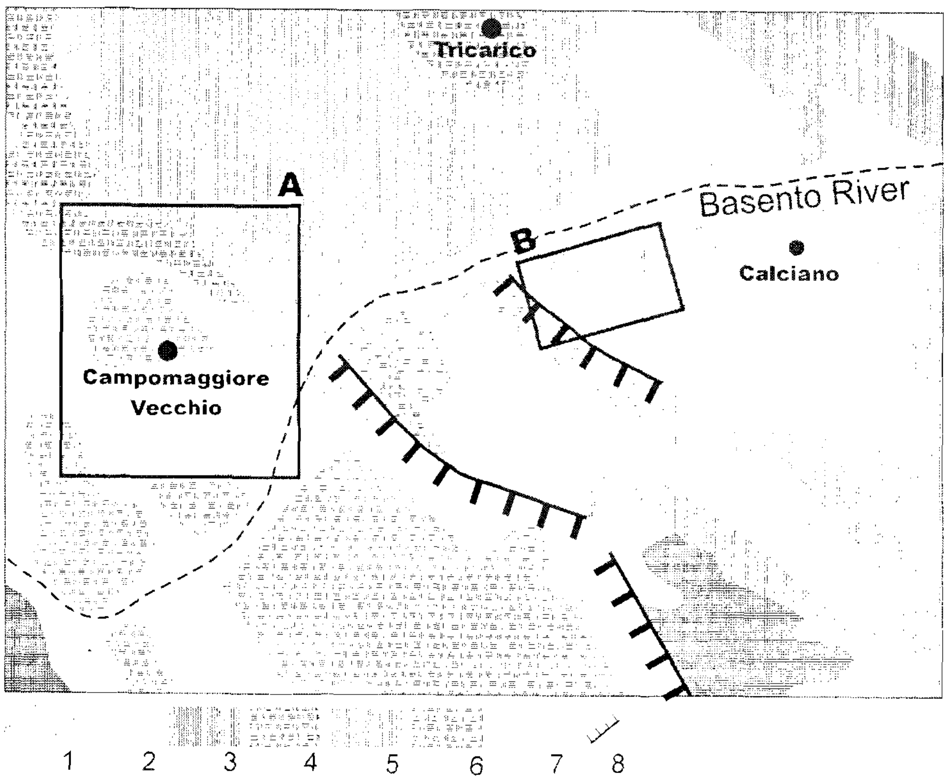

Figure 1: Geological outline and location of the area under study (after Bonardi *et al.*, 1988, modified). 1) Alluvial deposits; 2) Talus breccias; 3) Terraced conglomerates and sands (Middle Pleistocene); 4) Blue Clays (Lower Pleistocene – Upper Pliocene); 5) Serra Palazzo Formation (Lower Tortonian – Upper Langhian); 6) Numidian Flysch (Langhian – Upper Oligocene); 7) Red Flysch (Oligocene – Upper Cretaceous); 8) Overthrusts.

The attention is focused on one of the most significant landslides, reactivated by rainfalls occurred in May 1985 and in winter 1991, that has damaged the important railway line. The results of geological, geomorphological and hydrological investigations carried out to better identify the geomorphological development of the deep-seated mass movement and the role played by rainfalls in triggering periodical reactivations are reported.

2 THE INVESTIGATED AREAS

As shown in Fig. 1, the investigated areas are located in the middle valley of the Basento River (Southern Italy). The areas, close to the overthrusting front of the Apennine tectonic units on the Plio-Pleistocene terrigenous deposits of the Bradanic Fossa, are characterised by complex geological setting constituted by some structurally complex formations, with high clay contents, in highly deformed and tectonised flysch facies. The lithological and mechanical properties and the morphological features make these geological formations particularly liable to slope instability phenomena. Figures 2 and 3 report the geomorphological features of many mass movements that affected the aforementioned areas. The landslides are of various types, often deep-seated and huge.The main predisposing factors of this diffuse proneness to landslide are: lithological, geotechnical and hydrogeological features and morphostructural setting of the outcropping soils; deformations and failures caused by ancient and inactive deep-seated gravitational slope deformations. The main triggering causes of actual and recent landslides are heavy rains and seismic events.

2.1 Mass movements in the Campomaggiore area

The Campomaggiore area (Figures 1 and 2) is characterised by two distinct geological formations which make up the Lagonegro Units: the Numidian Flysch and the Red Flysch (Bonardi *et al.*, 1988). These geological formations are highly fissured and deformed and affected by tectonic overthrusting and faults.

The Numidian Flysch (Langhian – Upper Oligocene) consists of highly compact quartzarenite arranged in layers and banks well stratified and highly fissured.

The Red Flysch (Oligocene - Upper Cretaceous) consists of finely scaly and sheared varicoloured clay and clay shales interbedded with layers of jasper, calcarenite and calcirudite rocks. The Red Flysch exhibits a sharply disturbed to chaotic structure with folding and squeezing.

The actual geomorphological configuration of the left side of the Basento River, stretching from the present-day to the old urban centre of Campomaggiore, is the result of complex morphogenetic dynamics influenced by ancient, recent and current mass movements of various types and sizes. The key geomorphological features of these mass movements are reported in figure 2. Some huge compound slides have occurred west of Pietra del Toro relief and damaged the provincial road which connects the urban centre with the *Basentana* motorway. This road, which is the only arterial road in the area, shows some evident failures, such as: fissures, sinking of the road surface, etc.

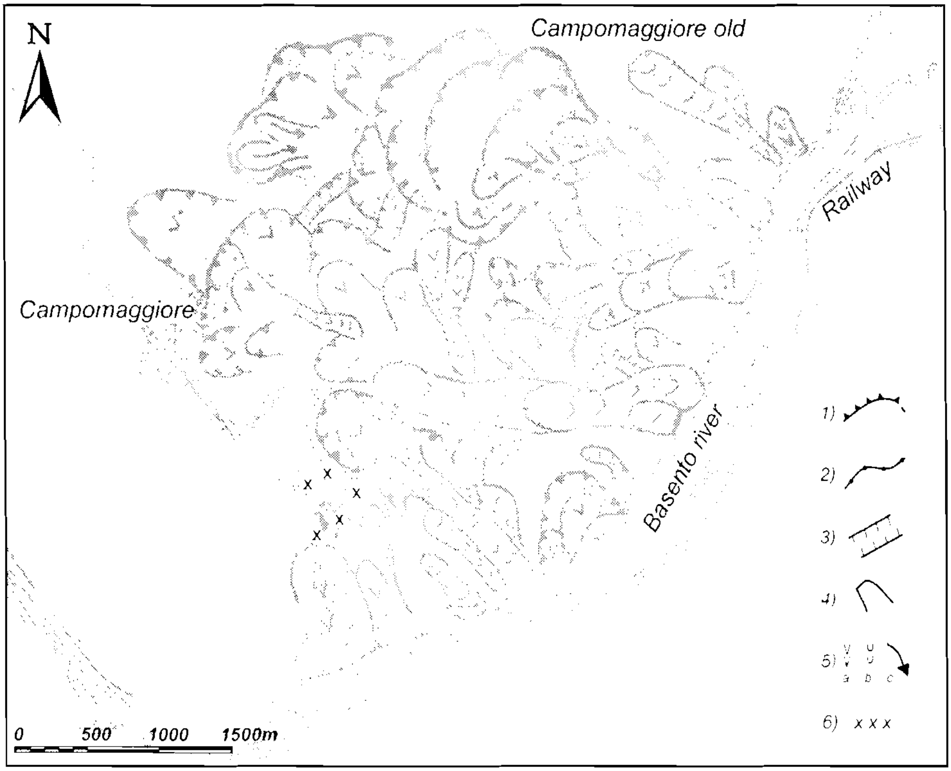

Figure 2: Mass movements in the Campomaggiore area. Geomorphologic map. 1) Landslide scarp; 2) fracture and rupture due to deep-seated gravitational slope deformation; 3) trenches resulting from deep- seated gravitational slope deformations; 4) landslide boundary; 5) compound slide a), earthflow b), rockfall c). 6) road parts periodically damaged by landslide

The area of old Campomaggiore is particularly liable to widespread slope instability phenomena. The slope as a whole, from the top (Montecrispo Mt.) to the Basento riverbed, is affected by advancing and multiple deep-seated compound slides which partially develop into large earthflows. This landslides are characterised by evident scarps, countersloping terrace and morphological depressions. Their thickness is safely bigger of some tens of meters. Along the ridges constituted by the Numidian Flysch (i.e. in Jazzo and Chiaromonte localities), some clear-cut morphological traits stand out (trenches, doubling crest dislocations, gravitational failures) which result from deep-seated gravitational deformations of the slope (i.e. lateral spreading), favoured by some predisposing factors, such as: marked upward slopes and high relief energy; complex geological setting constituted by highly fissured quartzarenite overlying plastic and deformable marly-clayey deposits of Red Flysch. The Numidiam Flysch is also prone to diffuse rockfalls and shallow translational slides.

One of the most significant landslides in the old town of Campomaggiore was an huge and ancient compound slide, the slow reactivation of which on the night of February 10, 1885, made the abandoning of the town mandatory. This landslide, with a gently main scarp that runs at 540-550 m a.s.l., encompasses a slightly countersloping terrace, above which the old town of Campomaggiore has been built (Figure 2) (Sdao and Simeone, 1996).

These large mass movements are not active to a large extent, though traces and elements from periodical reactivations, (well defined scarps and fissures, superimposed shallow debris bodies, ecc.) can be observed within them. These widespread and periodical renewals of movement repeatedly cause severe damage to the road network which connects the urban centre of Campomaggiore with a number of farm-houses and countryside roads, thus causing much inconvenience.

2.2 Slope instability in the area between Calciano and Serra San Domenico

This area is located along the right side of the medium Basento Valley and is traversed by the Potenza - Metaponto railway line and the Basentana motorway (Figure 3). The Serra Palazzo Formation outcrops in the area, whereas the Numidian Flysch is found only in some places. The latter overthusts the Serra Palazzo formation in Masseria Turato.

The Numidian Flysch (Langhian – Upper Oligocene) is constituted by cemented and stratified grey quartzarenite intercalated with marly clays and clayey marls.

The Serra Palazzo (Lower Tortonian – Upper Langhian) representing one of the complex formation from the structural and geotechnical standpoint. Such a formation consists of highly cemented sandstone, clayey marls, marly clays, limestone and calcarenite. These lithotypes are stratified in banks and layers and are heavily fractured.

The territory under study (Fig. 3), which covers an area of about 20 Km^2, shows diffuse morphological features and traces caused by deep-seated gravitational slope deformations refer to lateral spreadings and sackungs and by large landslides of compound slide type.

This slope instability phenomena are characterized by: considerable scarps, either clear-cut or degraded, failure surfaces, trenches (some of which very large in size), highly fractured areas and long open fissures, swelling zones, double ridge and undrained depressions.

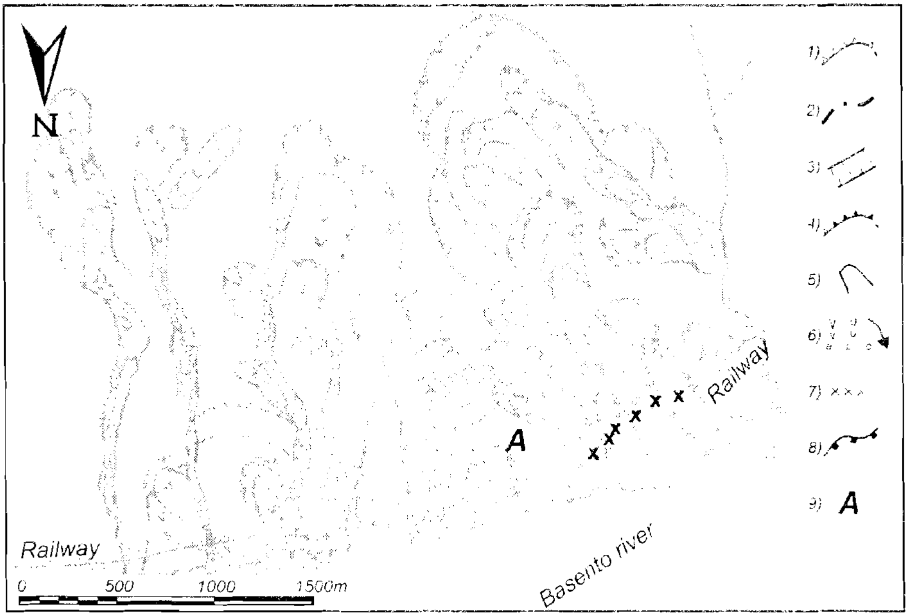

Figure 3: Deep-seated gravitational slope deformations and landslides along the right slope of the River Basento, near the town of Calciano. 1) main scarp of deep-seated gravitational slope deformation; when degraded are marked by a dotted line; 2) failure surface due to deep-seated gravitational slope deformation; 3) trench; 4) landslide scarp; 5) limit of landslide body; uncertain or degraded boundary are marked by a dotted line; 6) compound slide (a), earthflow (b) and prevailing longitudinal slow landslide; 7) railway line parts periodically damaged by landslide; 8) edge of the fluvial terrace; 9) location of Scaracelle landslide.

Along with the aforementioned mass movements, which are no longer active at present, a number of landslides are reported, mainly referred to compound and translational slides and earthflows. As shown in Figure 3, both the railway line and the Basentana motorway are often liable to landslides. Periodical and partial reactivations of these landslides cause failures and discomforts along the aforementioned railway line. Some periodical failures of the railway are reported at Masseria Turato, where a huge landslide mass is periodically reactivated.

3 Scaracelle landslide

Among the numerous landslides reported in the Calciano area, the attention is focused on a huge preexisting landslide mass in the vicinity of Scaracelle localily (landslide A in Figure 3, Figure 4). The most recent reactivations, following heavy rainfall events, occurred in May 1985 and in winter 1991; the former badly damaged the railway line that cuts the middle-lower portion of landslide body. Consolidation works of the landslide mass were started for safety reasons (Cotecchia and Monterisi, 1995). For the 1991 landslide event, hydrological data are not available; hence, account is given of the role of the rainfall in the reactivation occurred in May 1985.

3.1 Geomorphological features

Scaracelle landslide has affected the Serra Palazzo Formation and is originated and developed along the northern border of an area heavily affected by the already described deep-seated gravitational slope deformations and by major landslides (Figures 3 and 5).

It is an ancient and deep multiple compound slide with a roughly distinct well cut main scarp; its foot area is hid by recent and actual alluvial deposits of Basento River; the main sliding surface is located in marly-clayey soils at a deep of about 35 – 40 m (Figure 6). The main geomorphological and geometrical features are reported in Table 1.

	SC1	SC2
Area (Km^2)	0,15	0,05
Max length (m)	500	250
Max width (m)	300	200
Thickness (m)	35-40	20
Crown elev. m a.s.l.	400	325
Toe elev. m a.s.l.	230	240
Gradient (°)	20	18
Involved geology	Marly – clayey flysch	Ancient landslide debris

Table 1 Geomorphological and geometrical features of Scaracelle landslide (SC1) and 1985 landslide reactivation (SC2)

In May 1985 in the landslide body underwent a significant remobilitation (SC2 in Table 1, Figures 5 and 6) triggered by rains. This phenomenon predominantly affected the middle-lower portion of the pre-existing landslide body. In deep, the movement occurred along two different slide surface: the deeper one is located at about 20 m below field level.

3.2 Rainfall and May 1985 landslide reactivation

The rainfall regime in the area under study is typically Mediterranean and temperatures are moderate.

The low mean annual rainfall rate and the low mean annual temperature lead to a sub-humid climate.

Over 53 years of monitoring, the mean annual rainfall rate was 691 mm, with a monthly mean peak in November (88 mm) and a minimum value in July and August (29 mm).

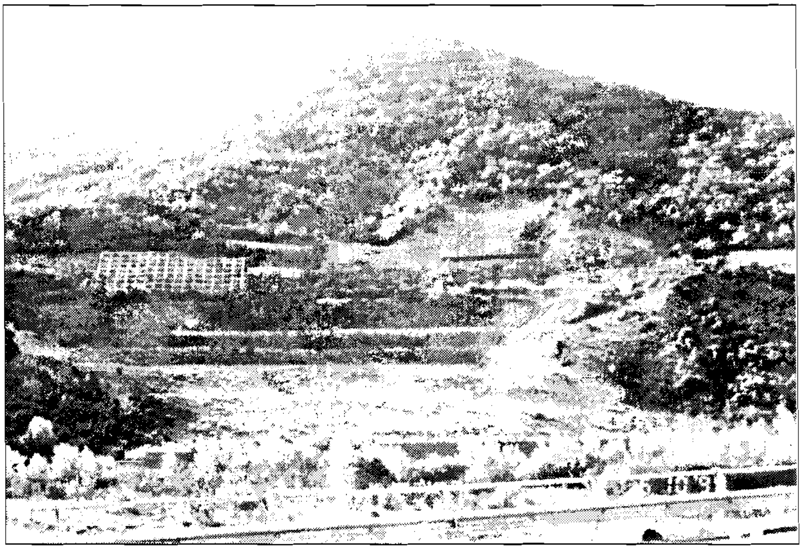

Figure 4: View of Scaracelle landslide. Scarps and landslide body are clearly visible. The arrow points to the railway line.

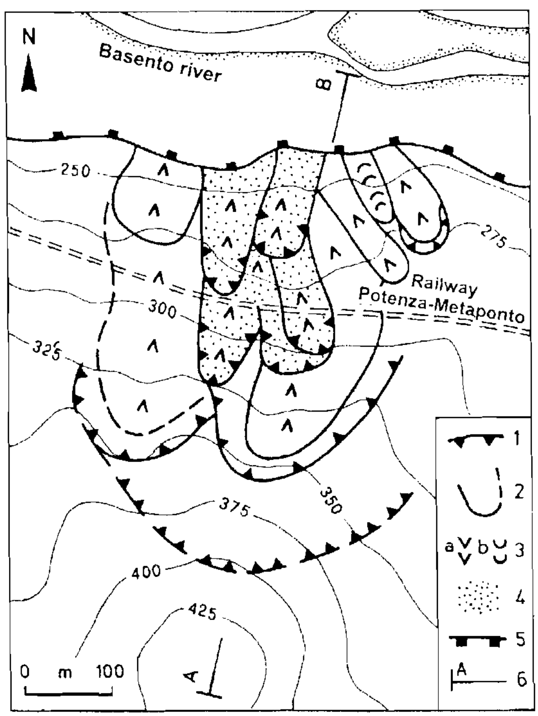

Figure 5: Scaracelle landslide – Geomorphological map. 1) landslide scarp; broken line wherever degraded, 2) boundary of the landslide mass; broken line wherever degraded or uncertain, 3) compound slide (a) and earthflow (b), 4) area affected by the May 1985 reactivation, 5) edge of the stream terrace, 6) cross-section trace.

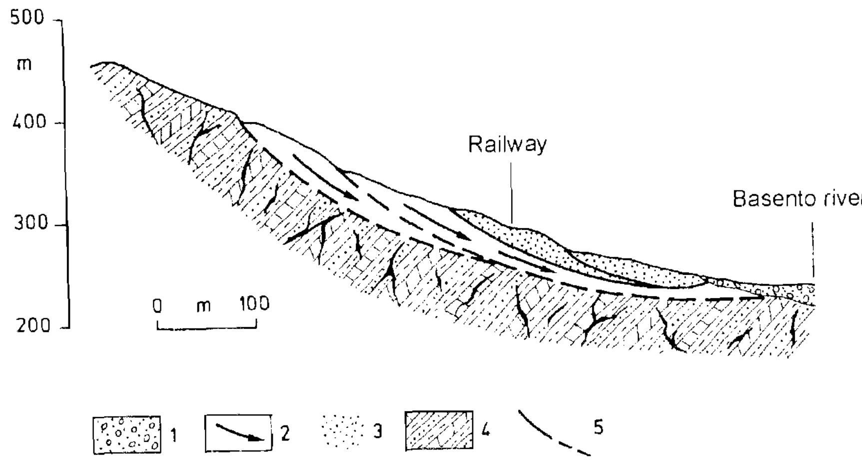

Figure 6: Geomorphological cross-section. 1) Current and recent alluvial deposits of the River Basento: 2) Landslide debris, 3) landslide masses reactivated in May 1985, 4) Serra Palazzo Formation affected by deep-seated slope gravitational deformations, 5) sliding surface; continuous line represents failure surfaces on which the May 1985 reactivation occurred

The Cumulative daily Rainfall (CR_{nj}) has been studied (Polemio 1997), where n ranged from 1 to 180 consecutive days, rainy or not, and j was the number of measurement days during the observation period (53 years). Daily rainfall data recorded at the Calciano rain gauge were then analysed for validation purposes. The short gaps in the data series were filled via a thorough comparative hydrological analysis of the catchment basin, based upon data yielded by the neighbouring gauges.

The peak values ($CRMAX_{n,y}$) were extrapolated per each single year y from the daily rainfall data. For each series of $CRMAX_{n,y}$ the parameters of the GEV (Generalised Extreme Value) probability distribution function have been calculated using the Probability-Weighted Moment method (PWM) (Hosking et al., 1985).

The search for foreign values yielded positive results for the series of cumulated records of 1, 5 and 10 days (Polemio, 1993). A single foreign value was reported for each variable (pertaining to the year 1972). In January 1972, a major flood hit most of the region (Basilicata), causing the overflowing of the Basento River and the Bradano River and damage to the Cavone and Agri Valley. Despite the heavy flooding, no significant slope stability phenomena were reported at Calciano. On January 19, 1972, 310 mm of rain were recorded at Calciano, thus defining the absolute peak daily value, 5.36 times the average of peak annual daily records.

In most of the Basilicata region, sustained downpours occurred in winter 1985 and caused widespread damage (Lazzari *et al.*, 1991). A period of frequent rainfalls started in Calciano in autumn 1984 and lasted up to May 1985. As a result, in mid-April 1985, cumulative rainfall from 120 to 180 days had reached high values (Figure 7). On the 19th of April, the 120-day and 180-day cumulative records attained a return period of 21 years and 67 years, respectively, the latter due to an unprecedented 944-mm rainfall. During the same period, all short-duration cumulative values were rather ordinary with a return period never exceeding 6 years. On receiving frequent daily and absolutely ordinary rainfall, long-duration cumulative values stayed high till late April. On the 9th of May, the 180-day cumulative value alone reached the absolute peak again.

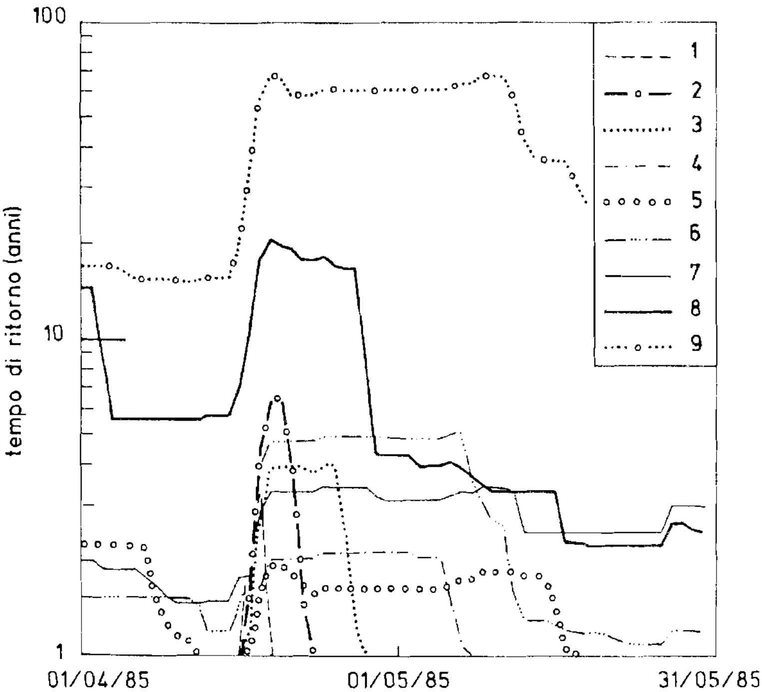

Figure 7: Return period of rainfall daily cumulated records pertaining to the 1985 reactivation. Cumulated rainfall for 1) one day;2) 5 days, 3) 10 days, 4) 20 days, 5) 30 days, 6) 60 days, 7) 90 days, 8) 120 days and 9) 180 days.

The above results imply that the re-activation in 1985 was presumably triggered by rainfall (Polemio and Sdao, 1996), particularly by long-duration rainfall.

Hence, it would be fair to assume that, starting from mid-April 1985, the slope instability phenomena may have slowly developed into a landslide, the earlier movements of which were reported during the last week of April and then gained momentum in May.

The hydrological and statistical outcome, defined regardless of the nature of the soils, was in line with the slope hydrogeological conditions and with the characteristics of the soils involved. Given the high incidence of cohesive grain-size fractions (Grassi *et al.*, 1993), the landslide mass can be associated to a low value of hydraulic conductivity which, based on the thickness of the landslide mass, allows to estimate a critical episode of infiltration of about 6 months.

4 Conclusions

Landslides cause frequently severe damage to road and railway facilities in the investigated area. The geomorphological characterisation of the slope evolution and the hydrological/statistical quantification of return period of rainfall are useful tools to define the type and the entity of the vulnerability of the local rail-road system hazard. The used hydrological/statistical method highlights the relevant role of long duration action of rainfall.

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