THE CONTRIBUTION OF SOIL SUCTION MEASUREMENTS TO THE ANALYSIS OF FLOWSLIDE TRIGGERING

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ABSTRACT: Flowslides affect many territories, including a large portion of the Campania Region (Southern Italy), where they have produced casualties and immense damage in recent years. A particularly tragic event occurred in May 1998, when 160 casualties were recorded in five little towns near Vesuvius volcano. To provide an answer within a short delay to the difficult and urgent demands of the Department of Civil Protection, geological and hydrological approaches were initially preferred. It was thus possible to recognise the existence of a residual risk for the urban areas affected by the flowslides of May 1998, and define a rainfall threshold for population security. Immediately after the first stage of the emergency, a geological model as well as preliminary geotechnical investigations and analyses highlighted the important role played by soil suction values in the triggering of flowslides. As a consequence, a detailed in situ and laboratory investigation program was set up to gain further knowledge of soil properties and suction values in the area under examination. After presenting a brief overview of the results of previous studies, this paper illustrates the processing of in situ measurements to obtain reliable information on soil suction regimen at both a small and a large scale. The results confirm the previous geological studies and show the reliability of geotechnical analyses, which seem to be the only means to verify, on a physical basis, the adequacy of the present warning system, and to plan appropriate stabilization works for the soil masses still in place.

Keywords: Suction, Landslide, Field instrumentation, Groundwater, Numerical modelling, Case histories

1 INTRODUCTION

Flowslides can be surely regarded as one of the most insidious forms of landslide, for several reasons: pre-failure evidence is not easily recognizable; in the post-failure phase the soil collapses and rapidly travels downslope; the initial mobilized volumes can increase as they travel downslope through the erosion of further soil masses.

As a consequence, flowslides involving different kind of soils, generally in a loose state, often produce casualties and tremendous economic damage (Sassa 1998). This is the case in Italy, and especially in the territory of Campania, whose mountains are diffusely covered with pyroclastic soils – generally in an unsaturated state – originated by the explosive phase of the Vesuvius volcano (Fig. 1). In this area, which has an extension of about 3000 square kilometres, the towns periodically threatened by flowslides are more than 200, as a historical analysis on flowslide occurrence has shown (O.U. 2.38 1998a; Migale, Milone 1998; Cascini, Ferlisi 2003).

Among recent destructive flowslide events (Fig. 1), one of the most calamitous occurred in May 1998 and caused 159 casualties and serious damages in four towns (Bracigliano, Quindici, Sarno and Siano), located at the toe of the Pizzo d'Alvano relief (Fig. 2).

Following this event, in order to provide useful answers within a short delay to the difficult and urgent demands addressed by the Department of Civil Protection (henceforth D.C.P.) to the University of Salerno, investigations and studies on the geology, geomorphology and hydrogeology of the limestone massif of Pizzo Alvano were considered of primary importance.

On the basis of such studies, a slope evolution model at a small scale was developed (Cascini et al. 2000). To verify the validity of this model from an engineering point of view, preliminary geotechnical analyses were performed at a more detailed scale (Cascini et al. 2000).These analyses proved the model to be valid. Accurate in situ and laboratory investigations were therefore planned in order to acquire further knowledge about the physical and mechanical properties of the soils as well as the in situ soil suction regimen.

After a brief description of previous investigations and studies, the present paper analyses soil suction measurements acquired over an approximately 30-month observation period in the zones where the huge flowslides were triggered. On the basis of the results obtained, some hypotheses are proposed on pore pressure regimen values at the failure stage with reference to a particularly representative flowslide chosen among those occurred on the slopes facing the town of Sarno.

Figure 1. Location Map.

2 PRELIMINARY INVESTIGATIONS AND ANALYSES

In May 1998, within an interval of about ten hours, flowslides occurred in almost all the basins of the Pizzo d'Alvano massif (Fig. 2). The triggering areas were located primarily in the upper parts of the basins. The average slope angle varied from 35 to 41 degrees and soil thickness ranged from 0.5 m to 5.0 m. The typical stratigraphic conditions of the triggering areas on mountain slopes within the territories of the towns of Bracigliano, Quindici, Sarno and Siano are illustrated in Figure 3. As can be seen, the slopes within the territory of Bracigliano show quite homogeneous stratigraphic conditions compared to those located in the territories of the other towns, due to a complete absence of pumice layers that in other slopes, and particularly at Sarno site, are present at different depths among the ashy layers (Fig. 3).

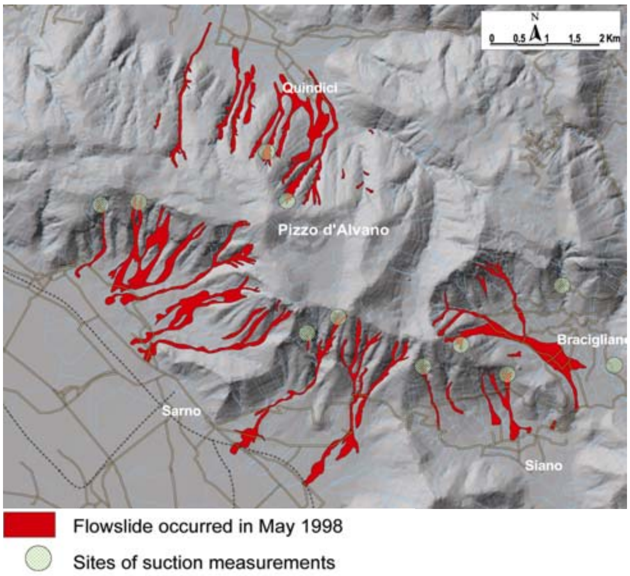

Figure 2. Plan view of flowslides occurred in May 1998 and sites of soil suction measurements.

In the majority of the triggering areas, multiple failures occurred. These failures progressively involved ample portions of the slopes, following mechanisms and time sequences that are not easy to reconstruct.

Post-failure movements resulted in flowslides, probably due to the generation of high pore water pressures which, in this and similar cases, some authors attribute to static liquefaction phenomena (Eckersley 1990; Olivares, Picarelli 2001; Wang, Sassa 2001). As flowslides travelled downslope, their initial volume increased mainly due to the erosion of the soil of the gullies below and, in some cases, through the incorporation of minor slides mobilised along the flanks of the gullies. The total volume of the landmass which invaded the downstream areas was estimated at about 3 million cubic meters. According to a back analysis of the damages suffered by buildings (Faella, Nigro 2001), the estimated velocities of flowslides in the urbanised areas ranged from 1 to 20 m/s.

Although flowslides in pyroclastic soils have often occurred during the last few centuries in the territory of Campania, they did not receive in the past adequate attention from the scientific community, especially as regards geological and triggering factors. In fact, the existing literature at the time of flowslide events dealt only with the assessment of the water-supply potentiality of the limestone bedrock (Civita et al. 1975; Celico, De Riso 1978; Cinque et al. 1987; Cascini, Cascini 1994), or the mechanical characteristics of pyroclastic soils in the hinterland of Naples (Pellegrino 1967; Nicotera 1998). That is why - along with other activities undertaken to support the D.C.P. - the University of Salerno set up an interdisciplinary research program (O.U. 2.38, 1998b) to deeply investigate the area affected by the 1998 flowslides. In particular, studies were devoted to: the assessment of geological, geomorphological and hydrogeological features of Pizzo d'Alvano massif at different scales (1: 25.000 and 1: 5.000); the carrying out of geotechnical analysis on flowslide triggering at a more detailed scale (1: 2.000); the mechanical characterization of pyroclastic soils; the assessment of in situ soil suction regimen.

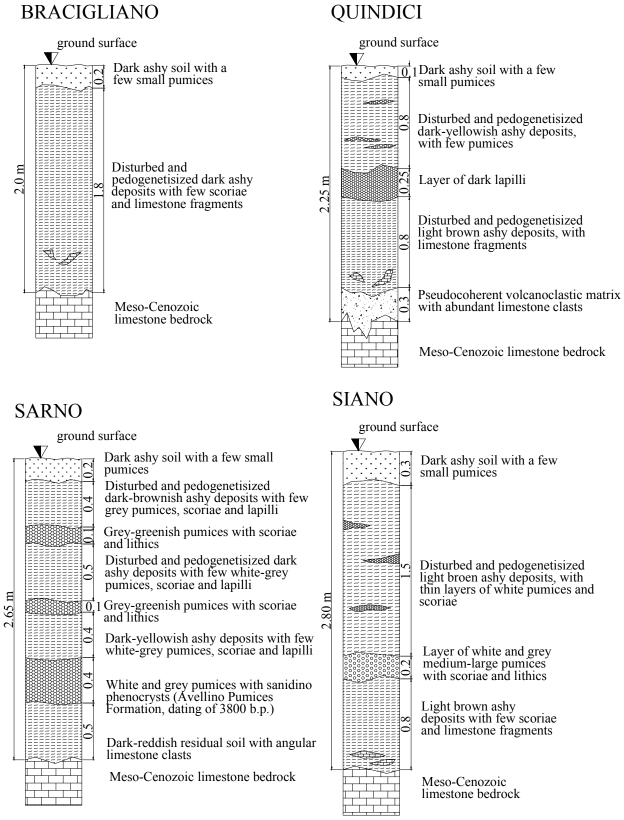

Figure 3. Typical stratigraphic sections of the investigation sites.

As far as the first three topics are concerned, the results obtained so far are illustrated in detail in Cascini et al. (2000, 2003), Bilotta, Foresta (2002), Sorbino, Foresta (2002) and Bilotta et al. (in prep.).

In particular, Cascini et al. (2000) present a slope evolution model capable of interpreting, from a geological point of view, past and recent flowslides in the area of Figure 2. This model shows that the triggering areas of flowslides are mostly located in particular morphological concavities (of the type known as "Zero Order Basins") formed by paleo-drainage networks of limestone bedrock (Guida 2003).

These concavities are filled with air-fall pyroclastic deposits and colluvial pyroclastic soils from upstream slopes. The model also stresses the important role played in flowslide triggering by temporary bedrock springs (or outlets), which are mostly located inside the ZOB areas (Fig. 4).

The above-quoted paper (Cascini et al. 2000) also contains a preliminary geotechnical back-analysis of the failure conditions of a particularly huge flowslide among those occurred in May 1998. The geotechnical analysis presented in this paper is based on scarce laboratory data on the mechanical properties of pyroclastic soils and a limited number of in situ soil suction measurements performed in the dry periods (June and July, 1998). Despite these limitations, the simulated time sequence of the instability phenomena agrees with the sequence of events reported by witnesses at the time of the failure. Moreover, the analysis confirms the importance of bedrock outlets, as well as the decisive influence of the negative pore pressure regimen on the stability conditions of the pyroclastic covers (Cascini et al. 2000).

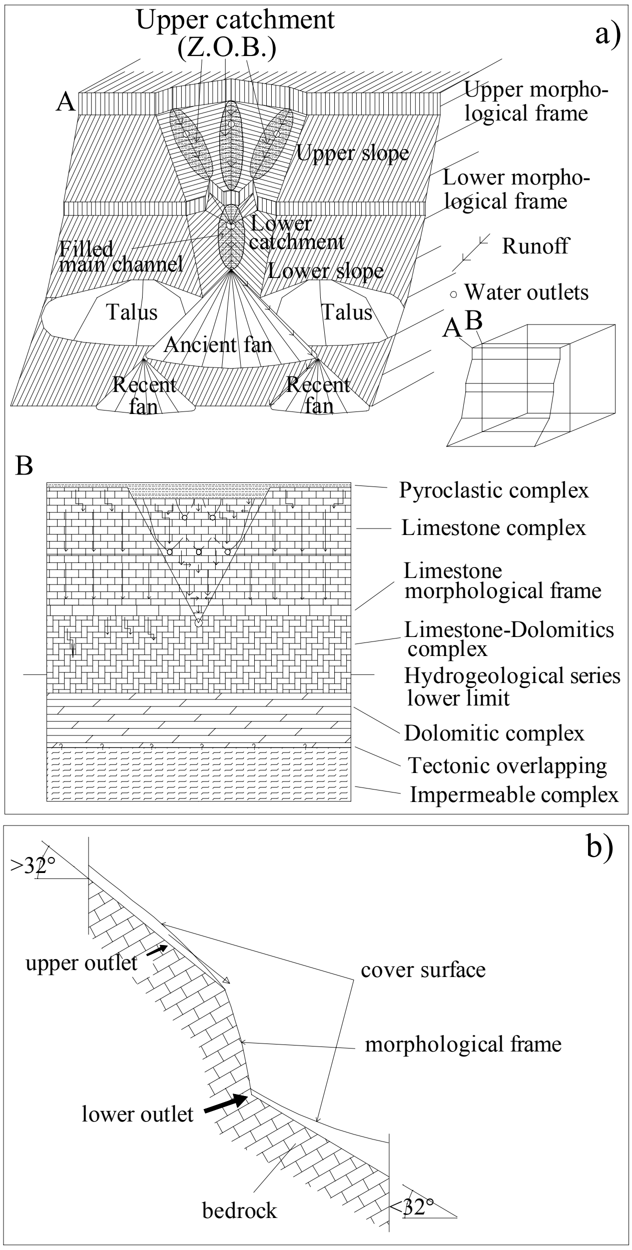

Figure 4. a) preliminary hydro-geomorfological model; b) typical location of the bedrock outlets (from Cascini et al. 2000).

As regards the mechanical characteristics of the pyroclastic soils, data published in Bilotta, Foresta (2002) Sorbino, Foresta (2002), Bilotta et al. (in prep.) concerning their grain size distribution and main physical properties, are shown in Figure 5 and Table 1. As Figure 5 clearly shows, the ashy soils are composed by prevailing sandy and silty components, sometimes with the presence of pumices (gravelly component) whose percentage by weight does not exceed 22%. Pumices, instead, are always constituted by a coarser material with a gravel percentage reaching, in some cases, values of 90%.

As for the other physical properties (Tab.1), it must be noted that ashy soils and pumices are characterised by high porosity (n) and quite low values of both specific gravity (Gs) and degree of saturation (S_r); these circumstances make the analysed pyroclastic soils a very light materials, as testified by the low values attained by the total unit weight (γ).

Turning to strength properties, Bilotta, Foresta (2002) performed a series of direct shear tests on undisturbed specimens, at natural water content (unsaturated state) and in saturated conditions, as well as on remoulded specimens; the experimental ongoing program also included suction controlled triaxial tests (Bilotta et al. in prep.). Results obtained from direct shear tests on saturated undisturbed specimens showed a Mohr-Coulomb failure envelope characterised by an effective friction angle φ' ranging from 30 degrees to 37 degrees and very low values of effective cohesion (not exceeding 5.0 kPa), which indicates that particle bonding does not occur in the examined ashy soils. Remoulded saturated specimens show higher friction angle values ($41° \le \varphi' \le 42°$), indubitably depending on lower porosity values compared to undisturbed conditions (Bilotta, Foresta 2002; Bilotta et al. in prep.). As for shear strength of ashy soils in unsaturated condition, Bilotta et al. (in prep.) found a well-defined relationships among shear stress at failure, net vertical stress and matric suction utilising the results of suction controlled triaxial tests and data coming from an original interpretation of direct shear tests conducted at natural water content. Those relationships evidenced, among the other features, a strongly non-linear envelope of shear stress at failure in respect to suction.

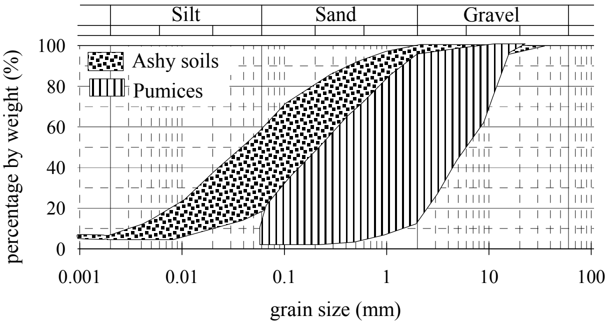

Figure 5. Grain size distributions of ashy soils and pumices (from Bilotta et al. (in prep.).

Table 1. Average values of the main physical properties of pyroclastic soils of Pizzo d'Alvano massif.

	G_s	n	γ (kN/m^3)	γ_d (kN/m^3)	w_n (%)	S_r (%)
Ashy soils	2.512	0.659	12.04	8.31	45.67	56.69
Pumices	2.314	0.689	9.02	7.20	25.34	26.47

Hydraulic properties of the ashy soils were investigated by Sorbino, Foresta (2002) on undisturbed specimens collected in the triggering areas of Sarno slopes. In particular, for saturated conditions, conventional permeameter tests were performed while, in the unsaturated ones, three different laboratory equipments were utilised, i.e. Suction Controlled Oedometer, Volumetric Pressure Plate Extractor and Richards Pressure Plate. In saturated conditions the estimated values of hydraulic conductivity were found to be ranging from a minimum of 5.0×10^{-6} m/s to a maximum of 4.8×10^{-5} m/s.

The results coming from the tests in unsaturated conditions are reported in Figure 6, where the volumetric water content and hydraulic conductivity are both plotted against suction by means of the best fit curves obtained by adopting the models of van Genuchten (1980) and Mualem (1976). For these unsaturated hydraulic characteristics, Sorbino, Foresta (2002) have ascertained a lack of influence of net total stress and the absence of any significant hysteretic behaviour within a 0 – 20 kPa range of the net total stress. With reference to net vertical stress values greater than 20 kPa, experimental results evidenced the influence of this last variable, with a progressive flattening of the soil-water characteristic curve, and the presence of small hysteretic behaviour mainly due to the presence of collapse phenomena.

Finally, as regards negative pore pressure inside the pyroclastic covers of Figure 2, Cascini, Sorbino (2002), presenting soil suction measurements collected over a period of approximately 20 months (from November 1999 to June 2001), evidence the possibility of data processing and so the necessity to continue soil suction measurements.

The analysis of all the data up to now collected, as well as the relationship between the soil suction regimen and flowslide triggering, will be illustrated in the next section.

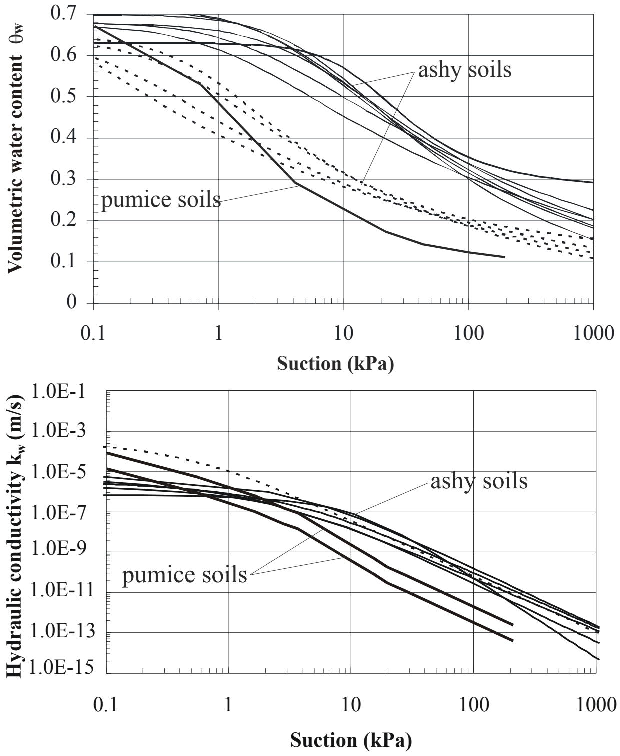

Figure 6. Unsaturated hydraulic properties of some ashy soils in the ZOB areas of Sarno town (modified from Sorbino, Foresta 2002).

3 SOIL SUCTION AND FLOWSLIDE TRIGGERING

3.1 *In situ measurements*

The acquisition of suction data in the area under examination began in November 1999 and, up to April 2002, a total of 2796 measurements were available. These measurements were mainly carried out during three distinct periods (Fig. 7).

During the first period (November 1999 – January 2001), data were collected all over the Pizzo d'Alvano massif. Measurements were taken, on average, twice a month at each investigation site. The lack of measurements in the first two months of winter, 2000, is due to logistic and organizational problems.

Measurements taken during the second and third period (respectively, February – July 2001, and November 2001 – April 2002) mostly refer to Sarno, where data were also collected, on average, twice a month. Data for the Quindici site were recorded at the beginning of the second period and at the end of the third one. The drastic reduction of measurements during these last periods is related to a progressive decrease of funding.

In situ measurements were performed using two different devices, viz., portable tensiometers (Quick Draw Tensiometers) and Jetfill in-place tensiometers.

Quick Draw measurements began in November 1999. At each investigation site, data were collected at different depths from ground surface. Due to the simple technology (pick and shovel) employed for the digging of the pits, maximum depths did not exceed 1.60 m.

The Jetfill in-place tensiometers were installed about 11 months after the beginning of measurements. A maximum of 3 tensiometers were arranged along the same vertical, with tip installation depths varying from a minimum of 1.5 to a maximum of 4.0 m. For many reasons, including the need for constant maintenance, the Jetfill tensiometers did not always provide a meaningful contribution. As a consequence, the number of useful measurements – mostly taken in the second period of Figure 7 – is very low.

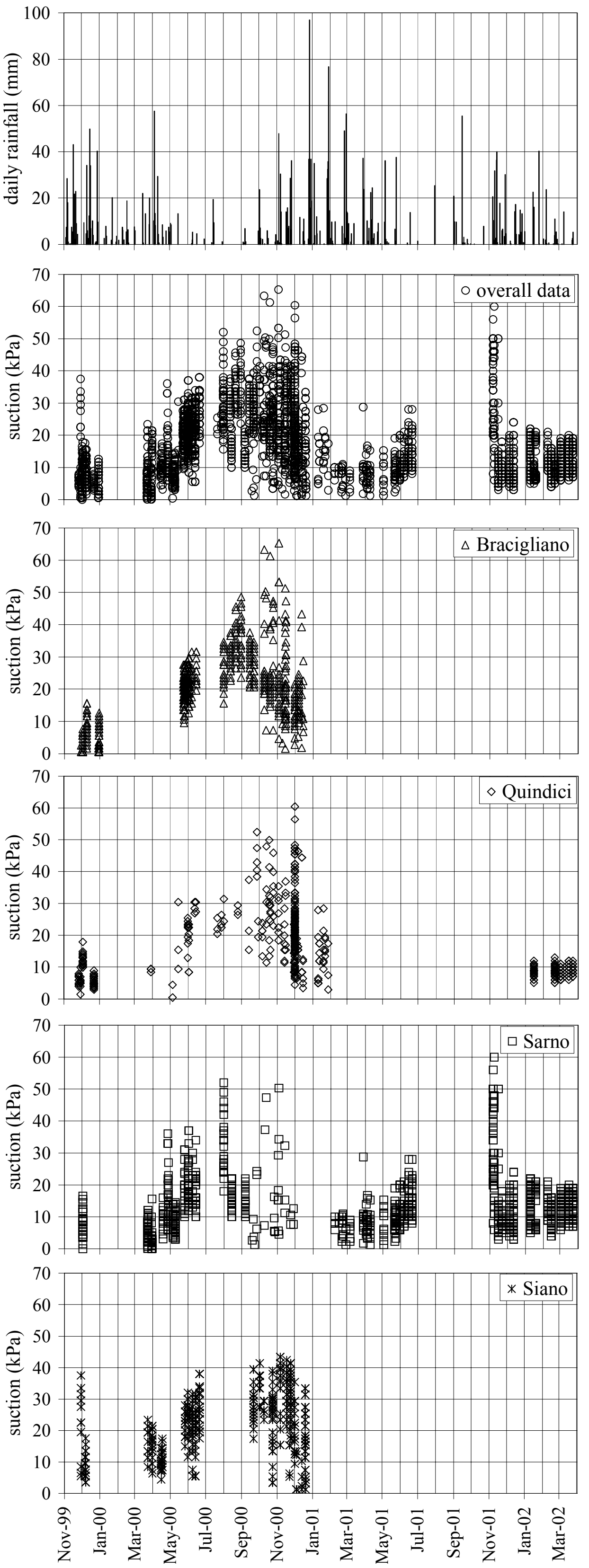

Figure 7. Suction data collected at the investigation sites and daily rainfall.

The investigated sites are essentially located in the triggering areas of the May 1998 flowslides (Fig. 2). On these sites, measurements were collected at different altitudes, both inside and outside the ZOB areas (Tab. 2), where local stratigraphic conditions vary from place to place.

Due to all the above considerations, the scattering of the rele-

Table 2. Investigations sites and performed soil suctions measurements.

		Number of measurements			
Investigation site	Average slope angle (°)	Quick Draw Tensiometer	Jetfill Tensiometer	Inside ZOB	Outside ZOB
Bracigliano	34	531	75	445	161
Quindici	35	488	-	424	64
Sarno	32	1142	93	1198	37
Siano	35	447	20	411	56

vant data when they are plotted in the same chart (Fig. 7) - without taking into account the depth, the altitude, and the site where they were collected - is not surprising. Nevertheless, in spite of this dispersion as well as of variations in the rainfall regimen throughout the observation periods (Fig. 7), all the data confirm the presence (Cascini, Sorbino 2002) of dry and wet periods during which suction values range from a minimum of 1-2 kPa to a maximum of 65 kPa.

3.2 *Soil suction regimen*

In order to verify if the data collected during the three observation periods were representative of all the flowslide triggering areas of the Pizzo d'Alvano massif, a preliminary analysis was carried out for the period ranging from March 2000 to February 2001, during which measurements were available at each investigation site, with negligible exceptions.

Figure 8 shows an example of the daily average values recorded during this period at each site, at a depth of 0.4 m. As can be readily observed, suction behaviour seems strongly affected by local factors such as evapotraspiration rate, stratigraphic conditions, etc. (Blight 1997; Lerouеil 2001), especially in August and September. This seems also to hold true for average values calculated for bi-weekly intervals (Fig. 9a), while monthly average values appear to be steadier than the previous one (Fig. 9b).

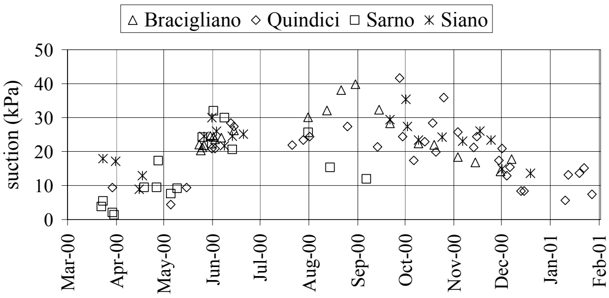

Figure 8. Daily average soil suction values at the depth of 0.4 m from ground surface.

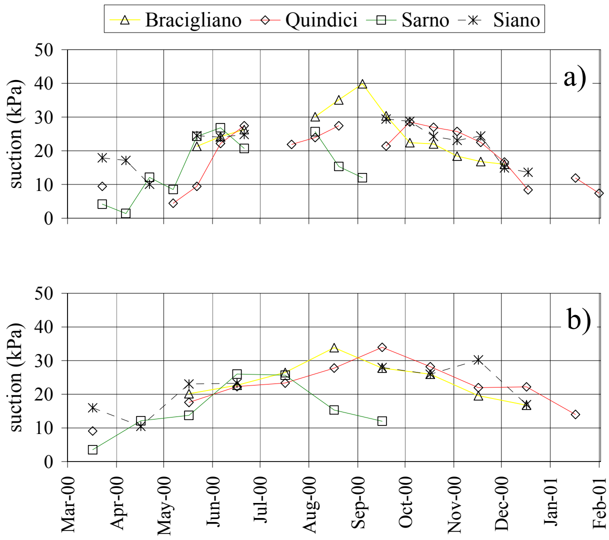

Figure 9. a) Bi-weekly average and b) monthly average of soil suction values at the depth of 0.4 m from ground surface.

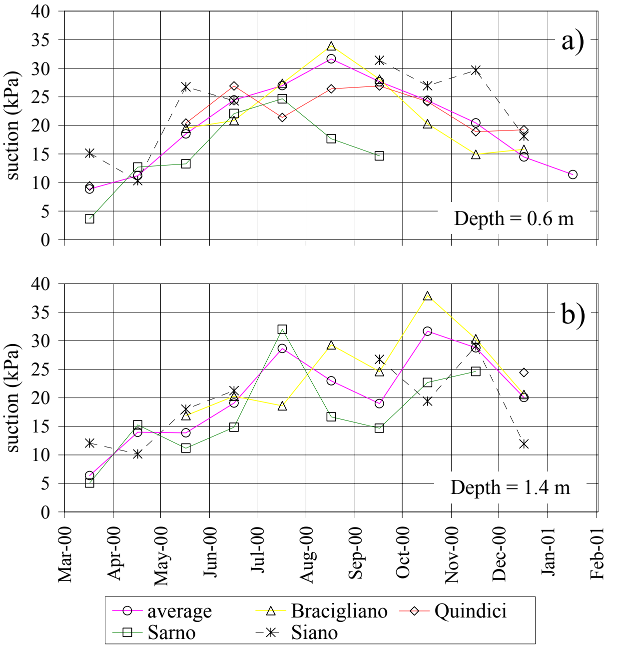

Figure 10. Typical monthly average suction values, a) at depths lower than 1.0 m and b) at depths higher than 1.0 m.

In particular, in the April-July and October-December (Fig. 10a) periods, at depths up to 1.0 m, monthly average suction values vary in a range not exceeding 15 kPa. Their variation appears to increase in the dry season (July – September), when the maximum scatter is slightly less than 20 kPa. In the same period, a tendency to faster saturation is observable on the slopes facing Sarno, probably due to the presence of many pumice layers (Fig. 3).

A similar trend can be observed at depths greater than 1.0 m (Fig. 10b), where differences in suction values are generally higher than at lower depths. It must be noted, however, that at these lower depths the suction time trend is not monotonic, as it attains two different relative maximum values, one in the summer, the other in early autumn.

Data scattering is reduced to a minimum when the monthly average refers to suction data collected at the same depths, independently of the measurement site (Fig. 11). In fact, the maximum difference – taking into account the different behaviour of the Sarno site in the period from August to September – is not greater than 10 kPa, both for depths lower than 1.0 m (Fig. 11a) and for depths greater than 1.0 m (Fig. 11b).

The foregoing analyses indicate that monthly average suction values – distinguished by depth, but not by site – calculated during the second and third observation periods can be considered typical of all the investigation sites. Monthly average suction values calculated over the whole observation period have hence been plotted taking into account only the depth at which each measurement was taken (Fig. 12). The monthly values for depths lower than 1.0 m (Fig. 12a) show an analogous trend, as do those for depths higher than 1.0 m (Fig. 12b). Moreover, for depths lower than 1.0 m the monthly suction regimen appears strongly related to rainfall (Fig. 12a).

These results invited two different analyses, one to ascertain relationships, if any, between monthly suction values and rainfall, the other to highlight suction regimen behaviour in time and in space.

Figure 13 shows monthly average suction values for all depths lower than 1.0 m compared with the moving average of daily rainfall over two and three-month periods. The suction values seem to agree with the moving average of daily rainfall over

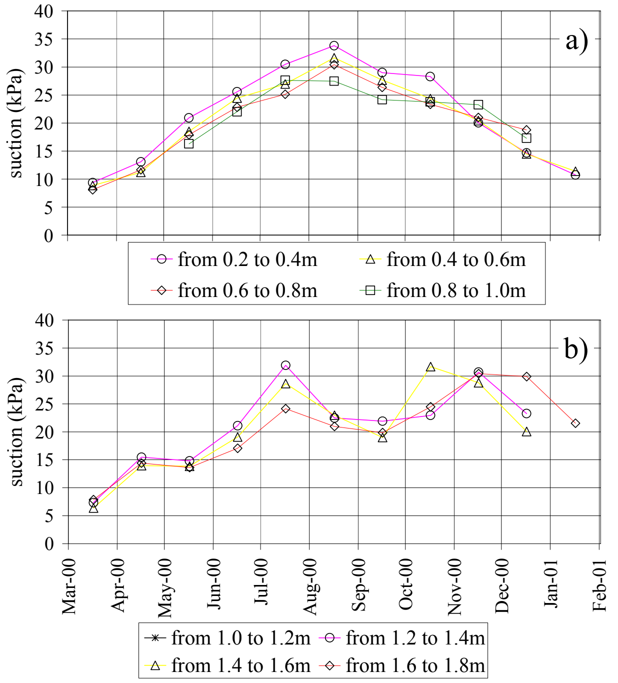

Figure 11. Monthly average of suction values collected at all the investigated sites, a) at depths lower than 1.0 m and b) at depths ranging from 1.0 m to 1.8 m.

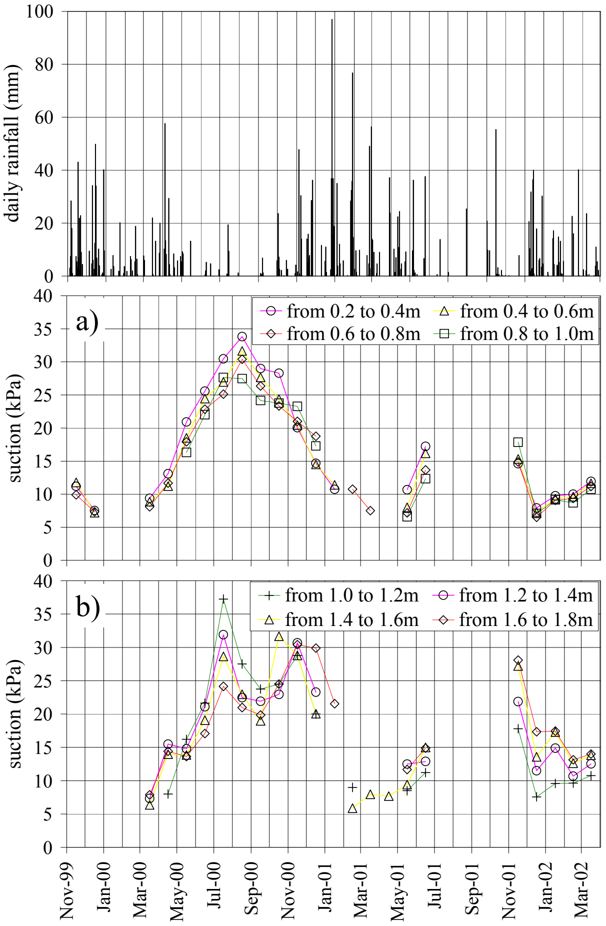

Figure 12. Daily rainfall and monthly average of suction values, a) at depths lower than 1.0 m and b) at depths ranging from 1.0 m to 1.8 m.

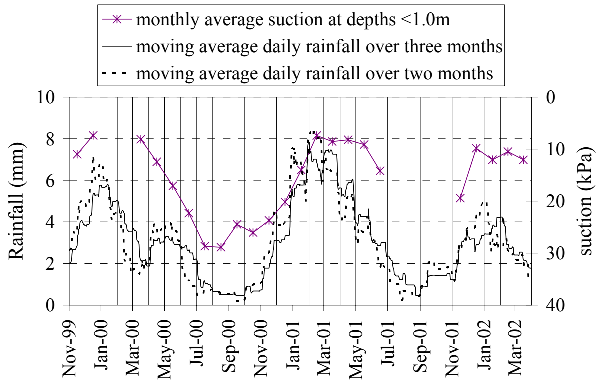

Figure 13. Comparison among monthly average suction values at depths lower than 1.0 m and the moving average daily rainfall over two-month and three-month period.

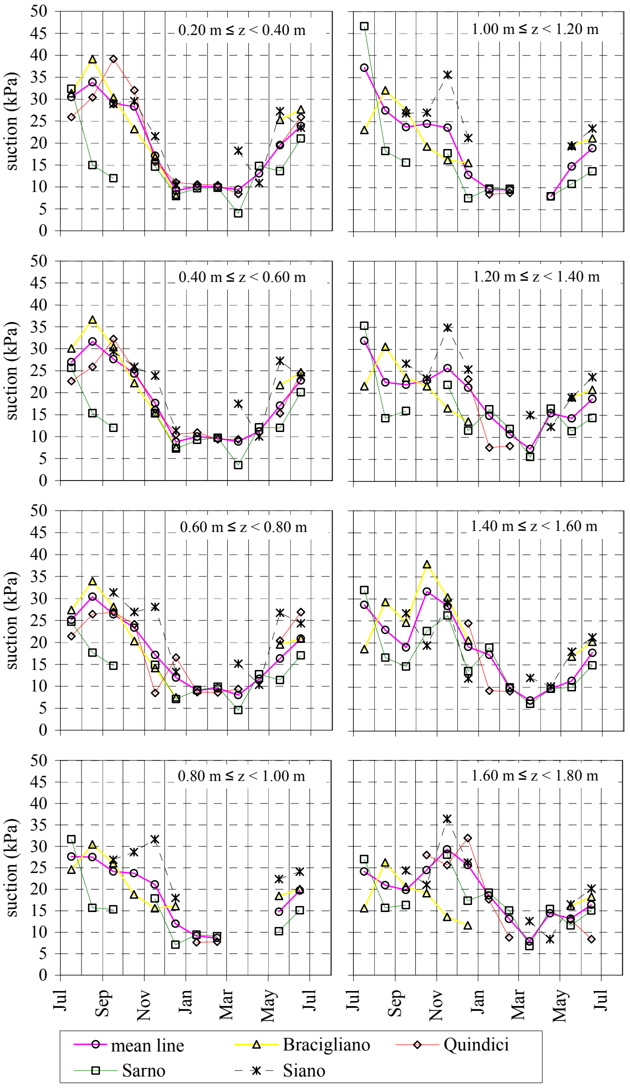

Figure 14. Soil suction monthly average at various depth (z) from the ground surface at the four investigation sites.

a three-month period. In particular, in spite of variations in the rainfall regimen during the observation period, the increase of suction at the beginning of dry periods (March – June) seems to be related to a moving average of daily rainfall over a three-month period not exceeding 4.0 mm. The same holds true for the beginning of the wet season (November – January), when the three-month period moving average above which suction decreases seems to be equal to about 2.0 mm (Fig. 13). As to suction behaviour regimen, it can be observed (Fig. 12) that, on a yearly scale, the time suction trend is quite similar during months when continuous measurements are available (e.g. November-December and May-June). Hence, it seems appropriate to analyse soil suction measurements on a monthly basis, independently of the year in which the measurements were taken.

Monthly suction averages for each investigation site and at various depths (z) up to 1.6 m are plotted in Figure 14, together with the "mean line" representing average soil suction values for the same depths at all the investigation sites.

Figure 14 shows that, for depths between ground surface and 1.0 m, monthly suction values attain their lowest value of 10 kPa in the January-March period at all the investigation sites. At lower depths, this period progressively decreases and seems to coincide with the month of April when, however, suction values do not differ significantly from 10kPa. Despite the lack of significant data, this value seems to be the same at depths between 1.8m to 4.0 m, as shown in Figure 15.

Also in this case, the Sarno site differs from the others, since it shows a more rapid decrease in suction values, especially at the end of summer and the beginning of autumn. Nevertheless, it is interesting to note that, in December and during the winter, monthly average suction values are everywhere equal to 10 kPa.

In conclusion, the foregoing analyses show that, all over the Pizzo d'Alvano massif, the monthly suction regimen seems to follow a regular trend during the wet season. To better illustrate this, the total head distributions with depth, obtained from the average soil suction values of Figure 14, are plotted in Figure 16. The figure shows that the unsaturated flow, during the wet season, is directed downward and characterized, for depths between ground surface and 1.0 m, by hydraulic gradients always very close to 1. In the same period, at lower depths, hydraulic gradients appear to be initially quite high, and progressively decrease with time, reflecting the advance of the wetting front (Fig. 16). Due to higher temperature and sun radiation during the dry season (April – August), suction increases and, owing to evaporation phenomena, hydraulic gradients seem to show variations in fluid flow direction at depths up to 0.6 m (Fig. 16).

In order to verify these hypotheses on the monthly suction regimen and to ascertain the existence of a relationship, if any, between monthly values and the flowslides triggering, a geotechnical analysis was carried out on a site where a large portion of the pyroclastic cover was mobilised in May 1998.

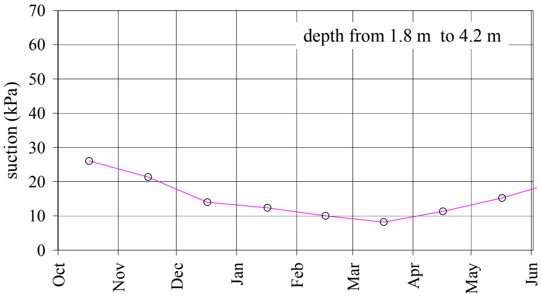

Figure 15. Monthly average suction values at depths ranging from 1.8 m to 4.0 m.

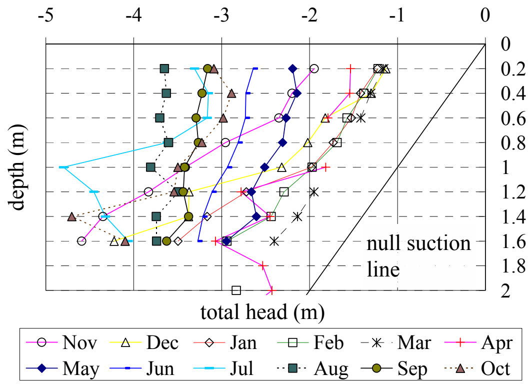

Figure 16. Monthly total head versus depth distribution.

3.3 *Considerations on flowslide triggering*

The analysis has regarded the same slope section already investigated by Cascini et al. (2003) and it has been enhanced by the availability of more detailed data on: the mechanical properties of pyroclastic soils summarised in Section 2; the high-scale (1: 2000) topographical surveys of triggering areas; the main features of negative pore pressure regimen evidenced by in-situ measurements. The localisation of the analysed slope section and its stratigraphic outline are furnished, respectively, in Figures 17a and 17b.

In particular, the analysis has concerned with the modelling of transient seepage regimen induced by rainfall and bedrock outlets inside the pyroclastic cover for the period January 1, 1998 – May 5, 1998; therefore, the computed pore pressure distributions were utilised for the evaluation of the safety factor at the time of failure occurrence, using limit equilibrium methods.

Referring to Cascini et al. (2003) for a detailed description of the methodological and numerical procedures adopted for the

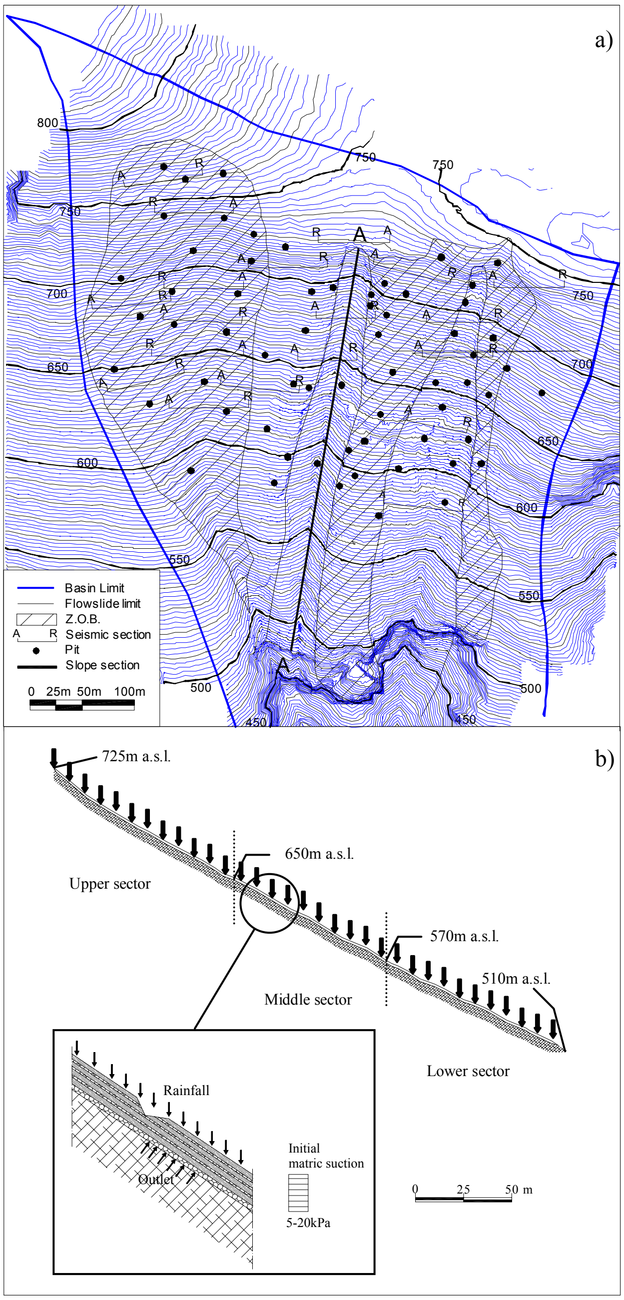

Figure 17. a) sample basin and field site plan facing Sarno town; b) stratigraphic section and initial conditions utilised for water flow transient analysis (modified from Cascini et al. 2003).

geotechnical analyses, the obtained results can be summarised as follows.

First of all, it can be observed that the presence of bedrock outlet is a key factor in order to allow the attainment of the failure conditions of the whole soil masses collapsed during the May 1998 event; in fact, if bedrock outlet is disregarded, only instability conditions affecting a small portion, located at the toe of the considered section, can be modelled. Moreover, a significant agreement between the simulated time sequence and the one deduced from the descriptions of eyewitnesses can be obtained by assuming an hydraulic conductivity of pumice layers equal to a mean value (7.5×10^{-5} m/s) of the range documented in the literature and considering, as initial condition at January 1, 1998, an uniform distribution of soil suction equal to 10 kPa all over the pyroclastic cover.

This suction value, which is in full agreement with the results deriving from the analysis of suction measurements at a yearly scale (Fig. 14), seems to reinforce the hypothesis that the regular trend of monthly suctions observed during the wet seasons, in the years following 1998, did characterise pyroclastic cover also during the early months (January – February) of 1998. This hypothesis seems to be confirmed by comparing the measured monthly suction values with those coming from the modelling of seepage conditions during the January 1, 1998 – May 5, 1998 period.

This comparison is reported in Figure 18 in terms of total head distributions with depth for some verticals chosen inside the three sectors (upper, middle and lower) of the analysed cross section (Fig. 17b). As can be seen, the computed total head distributions coming from the transient flow analysis agree with the total head distribution based on in-situ soil suction values (Fig. 18), for the January – March period. Significant differences arise, on the contrary, for the April - May period, when the flow regimen analysis indicates a total head distribution higher than those measured.

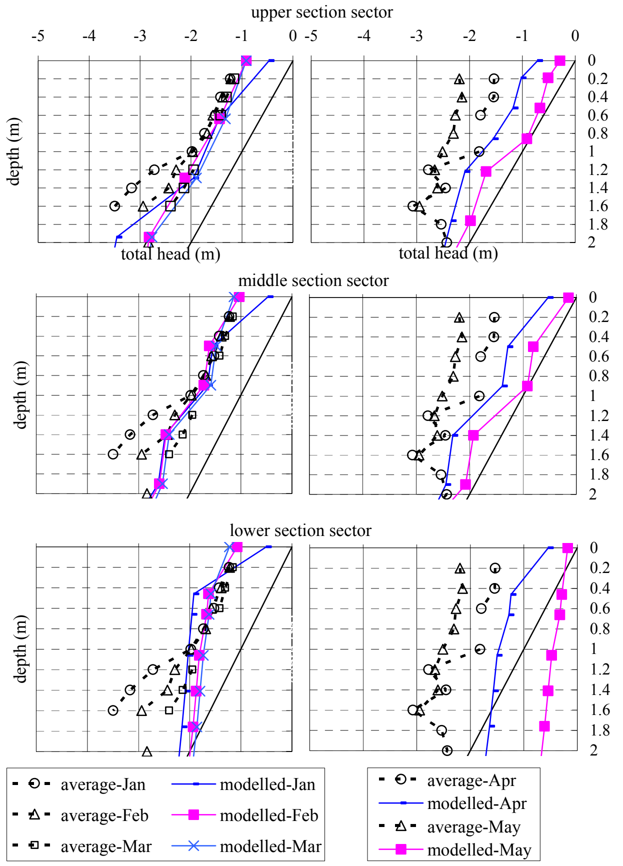

Figure 18. Comparison between monthly measured average total head and modelled total head.

At this respect, it can be observed that hydrological analyses carried out in order to characterise the rainfall events, before and during the flowslide occurrences, have evidenced recurrent rainfall events (return period of few years) during the months from January to March and a return period higher than 100 years for rainfall recorded during the period April – May 1998 (Rossi, Chirico 1998).

4 CONCLUDING REMARKS

Following the flowslide events occurred in May 1998, geological, geomorphological, hydrogeological and hydrological studies were initially preferred in order to assess the main physical features of the territory as well as to define the first emergency measures devoted to risk mitigation. At a subsequent stage, preliminary geotechnical analyses were performed on the triggering mechanisms of flowslides. Despite the poor data utilised in these analyses, the obtained results confirmed most of the hypotheses suggested by the previous geological studies; moreover they highlighted persistent unsaturated conditions of in situ pyroclastic soils before and during the flowslide occurrences. In consideration of this, a more detailed in situ and laboratory investigation program was planned. It was thus possible to acquire detailed data on the stratigraphic condition of the pyroclastic soils, on their mechanical properties, and on the soil suction regimen behaviour through space and time.

As suction values is concerned, analyses of all the collected data highlighted the main features of the unsaturated flow regimen inside the covers involved in the flowslide events and the possibility to relate suction values to rainfall. In particular, analyses indicated that monthly average suctions are characterized by the same behaviour at yearly scale, independently from the measurement site. Moreover, monthly suction values attain their lowest values of 10 kPa in the January-March period at all investigation sites and at any depth.

Finally, a detailed geotechnical analysis on the triggering mechanisms affecting the slope already investigated by Cascini et al (2000) evidenced that this monthly suction value can be assumed operating also in the wet season (January – March 1998) before the flowslide occurrences.

All these results are obviously in need of further confirmation, which can be attained by continuing soil suction measurements and applying the geotechnical models to other failure events which occurred on the slopes of the Pizzo d’Alvano massif. Moreover, some useful data could be derived from the historical analysis carried out so far on the occurrence of flowslides in the area and their seasonal distribution over the hydrologic year.

The results discussed in the present paper encourage the above investigations and studies which appear quite promising either to significantly contribute in determining the most appropriate stabilization works and, at the same time, in setting up warning systems physically based. Issues which are of great relevance not only for the area affected by the May 1998 flowslides, but also for the numerous Campanian towns exposed to analogous risks.

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