A Contribution to the Assessment of the Susceptibility to Sliding of Pyroclastic Soil Covers in Campania (Southern Italy)

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1. INTRODUCTION
Landslides in pyroclastic soils are very common phenomena in Campania. They are part of the natural morpho-evolution of a considerable part of the region. The pyroclastic soils derive from the alteration of airfall-sedimented layers of volcanic ashes and pumices, that were ejected by the Campi Flegrei and Vesuvius volcanic apparatuses during explosive eruptions. The soils can be found also at many tens of kilometers from the volcanic apparatuses, due to transport by wind following the eruptions. Many slopes in Campania, in carbonatic as well as in pyroclastic rocks, are extensively covered by such soils; it is commonplace to find them at slope angles that may exceed 45°, witnessing a remarkable and durable shear strength, essentially related to suction. Such shear strength however, while durable, is transient, as in some cases the soils fail and slide, particularly following intense and/or persistent rainfall. In historical as well as recent times, in Campania during storms many landslides originated within pyroclastic soils covering steep slopes. Generally such landslides display a complex style of activity (Cruden & Varnes, 1996), rapidly evolving into fast-moving debris flows, witnessing a solid-to-fluid transition of material behaviour after static failure (Olivares & Picarelli, 2001). Along their paths valleywards, the flows typically “bulk”, mobilizing everything but bedrock and incorporating also runoff water, thus increasing their volume and speed. The hazard in Campania still resulting from such landslides is proven by the damages and victims they have caused, also in recent years (Guadagno, 1991; Del Prete et al., 1998; Guadagno et al., 1999; Guadagno & Perriello Zampelli, 2000).

2. LANDSLIDES IN PYROCLASTIC SOILS: SUSCEPTIBILITY AND HAZARD
Following Varnes (1984), landslide hazard can be defined as the probability of occurrence of a landslide of a given intensity, in a specified area, within a given period of time. Landslide susceptibility can be considered as a subset of hazard, being (Soeters & Van Westen, 1996) the likelihood of occurrence of a landslide of a given intensity in a specified area. Assessing landslide susceptibility (“where” landslides of a given type can occur) is therefore essential in assessing landslide hazard (“where” and “when” they can occur), for which an assessment of the probability in time of the triggering event is also needed. With respect to complex landslides of damaging intensity in pyroclastic soils in Campania, it is well understood that the time of occurrence is related to rainfall intensity-duration patterns, although there do not seem to exist many significant data, and therefore agreement, on which patterns are the most likely to trigger the landslides. However it appears, as is well known for similar phenomena in residual soils and colluvium in other parts of the world, that the most dangerous patterns are those of prolonged rainfall, with rather intense precipitation at the end of the sequence (Guadagno & Perriello Zampelli, 2000). An example of assessment on a regional scale of susceptibility to similar landslides is in Morton et al., (2003). Being the slides triggered by rainfall, for Campania not much attention has been directed in the past to the characterization of the spatial susceptibility to sliding of the pyroclastic soil covers. In other words, the problem of determining where such landslides can take place, for a given triggering rainfall pattern that is evenly distributed within a specified area, has previously been investigated.
only secondarily. This can partially be explained by recognizing the fact that the spatial distribution of slides at a given time within a specified area is very often controlled also by non-homogeneous rainfall in that area. In fact, until 1998 the majority of damaging events resulted from landslides that were isolated, or very distant from each other, making it unattractive to investigate the dependence of their location on one or more character of the soil cover alone, separating them from the possibility of a spatially uneven distribution of the triggering event. In addition, the shape and geometry of the slopes covered by pyroclastic soils has been investigated perhaps less than other characters, such as land use, vegetation, past fires, etc. Regarding geometry, the literature points primarily to “hollows” (Ellen & Fleming, 1987) and to zero-order basins on the slopes as the locations where sliding failures can take place. However, attempts to apply quantitatively either of these concepts to past slides in pyroclastic soils in Campania yielded unsatisfactory results. In practical engineering terms, the current indetermination about where it is most likely that such slides can originate has made it impossible to devise “active” remedial measures, aimed at increasing local safety factors with respect to sliding failure, to be taken directly at critical locations on the slopes above vulnerable areas.

3. SCOPE OF THE WORK
In this work it is attempted to verify if there are some geometrical characters of the pyroclastic soil covers that do indeed control where sliding failures can take place. Such an attempt derived from a detailed inventory of the slides that occurred on May 5-6, 1998, on the slopes of the “Pizzo d’Alvano” relief (about 10 km E of the Vesuvius), whose transformation into debris flows caused much devastation in the towns of Sarno, Quindici, Siano and Bracigliano, at the slopes’ foot. Compared to other recent events in Campania, such slides were particular in the fact that they all (many tens of them) took place within few hours in a limited area around the top of the relief (Fig. 1), and therefore provide a consistent experimental data set. Its analysis conducted to the following hypotheses:

1) the preceding rainfall pattern can be considered as constant throughout the area;
2) the nature (including vegetation, aspect, past fires etc.) and shear strength properties of the pyroclastic soils where the slides originated can, as a first approximation, be considered as constant throughout the area;
3) the location of the slides was primarily controlled by the value of the slope angle, provided that the slope profile type prior to sliding were ascribed to either one of two classical soil mechanics’ schemes: infinite slope or finite slope.

Let us not discuss the first two hypotheses: let us only note that rainfall as well as nature and shear strength of the soils, while obvious primary controlling factors of failure, are simply being considered as not varying throughout the area.
The third hypothesis derives from the fact that, all other controlling factors being considered as constant, there must be different values of slope angle for which limiting equilibrium is reached, when:

a) the slope is sufficiently planar it can be analyzed as an infinite slope, with a continuous soil cover;
b) the slope, displaying a discontinuity in the soil cover and/or non-homogeneous inclination, has to be analyzed as a finite slope.

Such hypothesis stems from the observation that, on May 1998 on the Pizzo d’Alvano, a very significant percentage of the slides took place in the vicinity of a discontinuity of the soil cover (either track cuts or bedrock outcrops), at gentler threshold slope angle values than for nearby, virtually contemporary slides within continuous, pseudo-planar slopes (Table 1).

In the literature, on the other hand, inventories of landslides in pyroclastic soils (for example De Riso et al., 1999) traditionally report simply the slope angles where sliding failures took place, to be referred to an infinite slope scheme.
Due to the fact that landslides in pyroclastic soil covers occurred, and will presumably occur, in a considerable, very densely populated part of Campania, showing a geomorphological setting very similar to that of Pizzo d’Alvano, the verification of such hypotheses and the implementation of a usable, exportable deterministic method based on them represent the aim pursued in this work.

Table 1 – Some statistics of the sliding areas for the May 5-6, 1998, complex landslides on the Pizzo d’Alvano (only the main slides have been considered)
4. DATA COLLECTION AND ANALYSIS

In order to attempt to verify the validity of the hypotheses, a series of data had to be acquired and analyzed. It proved necessary:

- to generate a Digital Terrain Model of the area, as accurate as possible;
- to survey the pyroclastic soil covers and all their discontinuities in the area (prior to May 5, 1998), and position them on the DTM;
- to survey all the landslides of the area and position them on the DTM;
- to perform an analysis of the relationships among locations of initial slides, slope angle values and vicinity to discontinuities in the soil cover.

With respect to the first point, it has to be noted that the best available topographic data of the area are still the 1:5,000 technical maps of Southern Italy of the early 80’s: all the x,y,z, informations of such maps were digitized and georeferenced. From this it was possible to construct a 10 metre-cell grid DTM of the area. Other maps (official and unofficial), ranging from 1:25.000 to 1:5.000 and as recent as July 1998, were also carefully analyzed.

With respect to the second and third point, field activity and airphoto (from 1954 to July 1998) rectification, georeferencing and interpretation were performed. In addition, regarding the second point, it was possible to detect the presence of many tracks only through the same 1:5.000 maps that were used for the DTM. This is because many such tracks were abandoned over the years (while new ones were constructed), and therefore covered by vegetation, making it impossible to detect them in the field or on successive airphotos. On the other hand, their detection proved very important, because of the cut in the soil cover they continued to represent. The number of tracks on the Pizzo d’Alvano that are not visible anymore is very significant: this presumably applies also to other similar reliefs with pyroclastic soil covers in Campania.

5. GIS ANALYSIS; METHODS AND RESULTS

Analyzing the data summarized in Table 1, it was decided to pick two preliminary values of slope angle to be considered as critical with respect to landslide initiation: 40° for slopes that could be reconducted to an infinite slope scheme, and 30° for slopes that had to be reconducted to a finite slope scheme, because of discontinuities in the soil cover. Then, a series of GIS topological operations were performed; their first results can be summarized as follows:

1) identification of areas, covered by pyroclastic soils, whose slope angle ≥ 40° (Fig. 2);
2) identification of areas within 10 m of the border of bedrock outcrops or of the centreline of roads and tracks, covered by pyroclastic soils, whose slope angle ≥ 30° (Fig. 3).

The areas identified as just described can be considered as areas falling within the given susceptibility category; they represent a first attempt to determine the pre-May 5, 1998, susceptibility to sliding on the Pizzo d’Alvano for a triggering rainfall pattern such as that which preceded that date. Figure 4 shows the May 1998 landslides on the union of the above susceptibility categories.

It can be noted how the majority of the slides falls within the susceptible areas; this represents a first verification of the adopted hypotheses.

It has to be kept in mind that such agreement simply consists of the validation of a simple engineering geomorphological model, implemented in quantitative terms with respect to the experimental data whose analysis allowed for its devising.

On the other hand, it can be noted how several slides do not fall within the susceptible areas. Based on this observation, it was considered that perhaps referring to only two slope types and, consequently, slope angles, was too schematic. In particular, the infinite slope model is too unrealistic. Therefore it was hypothesized there existed a third slope scheme, where the soil cover is not discontinuous, but nevertheless it is not possible to reconduct it to an infinite slope. In this scheme a third, intermediate threshold slope angle value is identified, but only where the slope
Fig. 2 – Areas covered by pyroclastic soils whose slope angle $\geq 40^\circ$

Fig. 3 – Areas within 10 m of the border of bedrock outcrops or of the centreline of roads and tracks, covered by pyroclastic soils, whose slope angle $\geq 30^\circ$

curvature exceeds a given value. This resulted in the identification of a further susceptibility category:

3) areas covered by pyroclastic soils whose curvature $\geq \tan \tan 30^\circ$ and whose slope angle $\geq 35^\circ$ (Fig. 5).

The union of this further category (Fig. 6) to susceptibility helps in reducing the number of undetermined landslides.
Fig. 4 – Areas covered by pyroclastic soils whose slope angle $\geq 40^\circ$ (in red) and areas within 10 m of the border of bedrock outcrops or of the centreline of roads and tracks, covered by pyroclastic soils, whose slope angle $\geq 30^\circ$ (in green)

Fig. 5 – Areas covered by pyroclastic soils whose curvature $\geq \tan 30^\circ$ and whose slope angle $\geq 35^\circ$

6. CONCLUSIONS
The method presented herein is based on the hypothesis that there must exist different values of critical slope angle for sliding of a given pyroclastic soil cover under spatially homogeneous triggering conditions: such values are related to the static equilibrium of slopes that are assumed as having the same cover but different geometries. A safety factor equal to unity is reached at a slope angle value that is higher for pseudo-planar slopes than for slopes on which the continuity of the
cover is interrupted. In addition, this slope angle value is higher also than for slopes whose cover, while continuous, is curved.

The method has been devised and implemented with respect to the landslides of May 1998 on the Pizzo d’Alvano, which represent the most significant experimental data set available in Campania due to their number, together with their spatial and temporal concentration.

The implementation of the method towards the simulated prediction of where the slides of May 1998 on the Pizzo d’Alvano took place gave very good results. However the method, as implemented, showed an overestimation of the susceptibility to sliding, which proves that other spatial controlling factors, here considered as constant, should instead be accounted for. The method is open to the introduction of such factors. Also, the slope angle, distance from discontinuities, and curvature parameters can be varied.

It has to be pointed out, however, that the method relies heavily on data deriving from a Digital Terrain Model, and therefore on its representativeness and accuracy.

The method can and will be applied to other areas of Campania, as it appears potentially capable of providing significant results with respect to the determination of the susceptibility to sliding of pyroclastic soils, at least for slopes cut in carbonatic rocks.

LIST OF REFERENCES


