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GEOTECHNICAL INFLUENCE ON SOIL SLIPS IN THE APUAN ALPS (TUSCANY): FIRST RESULTS IN THE CARDOSO AREA

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ABSTRACT: The June 19th, 1996 exceptionally intense rainstorm triggered hundreds of soil slips in the southern Apuan Alps (Italy). Many surveys were carried out to characterize the slopes involved in mass movements, as regard the main geological and geomorphological factors of the landslide sites. Since not all the slopes with the same geological and geomorphological conditions had the same behaviour versus the stability, some preliminary geotechnical and hydrogeological surveys were carried out near Cardoso village. Here, the first results of these studies are summarized. Penetrometer and permeability tests were performed on site, and many samples were taken on both landslide sites and uninvolved slopes, to identify the grain size and the Atterberg limits. The laboratory tests pointed out the heterogeneous, prevalently granular, nature of the analyzed samples, due to the particular parent rock; furthermore, it seems that the landslide sites were characterized by finer material if compared to colluvium of similar slopes, without landslide phenomena. The Atterberg limits tests classify all the samples as medium to low plasticity material in the Casagrande Plasticity Chart, with low plasticity index as well. It seems also that in landslide sites material had a lower liquid limit respect to slopes not involved in mass movements. The on-site permeability tests seem confirm these results: in fact, the permeability coefficient seems to be lower for the slopes involved in landslides.
Keywords: Soil slips, Colluvium, Geotechnics, Tuscany, Italy

1 INTRODUCTION

Following the exceptionally heavy rains of June 19, 1996 (ca. 474 mm rainfall was recorded within 12 hours – ca. 21% of the annual rainfall), the southern portion of the Apuan Alps (northwest Tuscany) was affected by several hundreds of shallow landslides (soil slips-debris flows – Campbell 1974). This contributed to the formation of hyperconcentrated debris flows in the main torrents, devastating the villages at the valley bottom and causing a total of 14 deaths. These landslides, attributable according to Cruden, Varnes (1996), to complex debris/earth slide – debris/earth flow, with class of velocity ranging from very to extremely rapid, involved almost exclusively shallow regolith covers of impermeable and semi-impermeable rocks, with thickness that rarely reached or exceeded two metres. The area most affected by the downpour was the basin of the Cardoso Torrent, a small mountain sub-basin of the River Versilia. The studies carried out on the landslide movements in this zone (D'Amato Avanzi et al. 2000, 2002) highlighted some characteristics (prevalently geological and geomorphological) that recur in the landslide sites. Since not all the slopes with similar geological and geomorphological features were affected by soil slips, it was considered opportune to carry out further surveys on sample slopes, in order to evaluate their main geotechnical and hydrogeological parameters and to contribute to evaluate the trigger mechanism.

This paper presents the preliminary results obtained in these surveys, carried out in some zones of the area around Cardoso village (Upper Versilia) and particularly affected by the shallow landslides of June 19 1996. The aim is to identify and quantify possible analogies or differences in the geotechnical and hydrogeological characteristics of apparently similar slopes from a geological and geomorphological point of view, but which presented different behaviours with respect to stability on the occasion of the rainfall of June 1996.

2 GEOMORPHOLOGICAL AND GEOLOGICAL FEATURES OF THE AREA

The basin of the Cardoso Torrent, situated in the southern zone of the Apuan Alps, in the Versilian hinterland (north-western Tuscany) (Fig. 1), constitutes one of the mountain ramifications that give rise to the River Versilia. The basin is delimited by a watershed of which the best-known peaks of the Apuan Alps are a part: Mt. Pania della Croce (1859 m), Mt. Forato (1230 m) and Mt. Procinto (1161 m). The study area presents an extension of about 13 km^2, with high values of the slopes gradient: the highest peak is the Mt. Pania della Croce (1859 m), while the lowest corresponds to Pontestazzemese (163 m), which is the closing section of the basin. The zone is therefore a typical mountain basin, characterized by fairly narrow and incised valleys and markedly steep slopes.

From a geological point of view, the basin of the Cardoso Torrent falls in the area characterized by the outcrop of formations belonging to the Autochthonous *Auctt.*, among which the Pseudomacigno Formation (quartzy-feldspar-micaceous, grey-coloured, metamorphic sandstone, interbedded with levels of dark-blackish grey shale) represents the most common one, especially around the village of Cardoso (Carmignani et al. 2000). In the coarser grained levels of the Pseudomacigno Fm., the "Cardoso Stone", the precious ornamental stone commonly used for building, is extracted.

The morphology of the zone is considerably influenced by the geological-structural context of the Apuan area. The ridges that delimit the basin are generally constituted by calcareous spurs with walls with gradients greater than 60 degrees, often subvertical.

The calcareous walls are linked to the lower portions of the slopes, modelled prevalently in metarenaceous and schistose-phyllite rocks, through accumulations of debris and scree slopes. These accumulations are generally covered by sparse arboreous, but more often shrub and herbaceous vegetation, while in some cases they are completely devoid of vegetation, showing that the process of accumulation is still active.

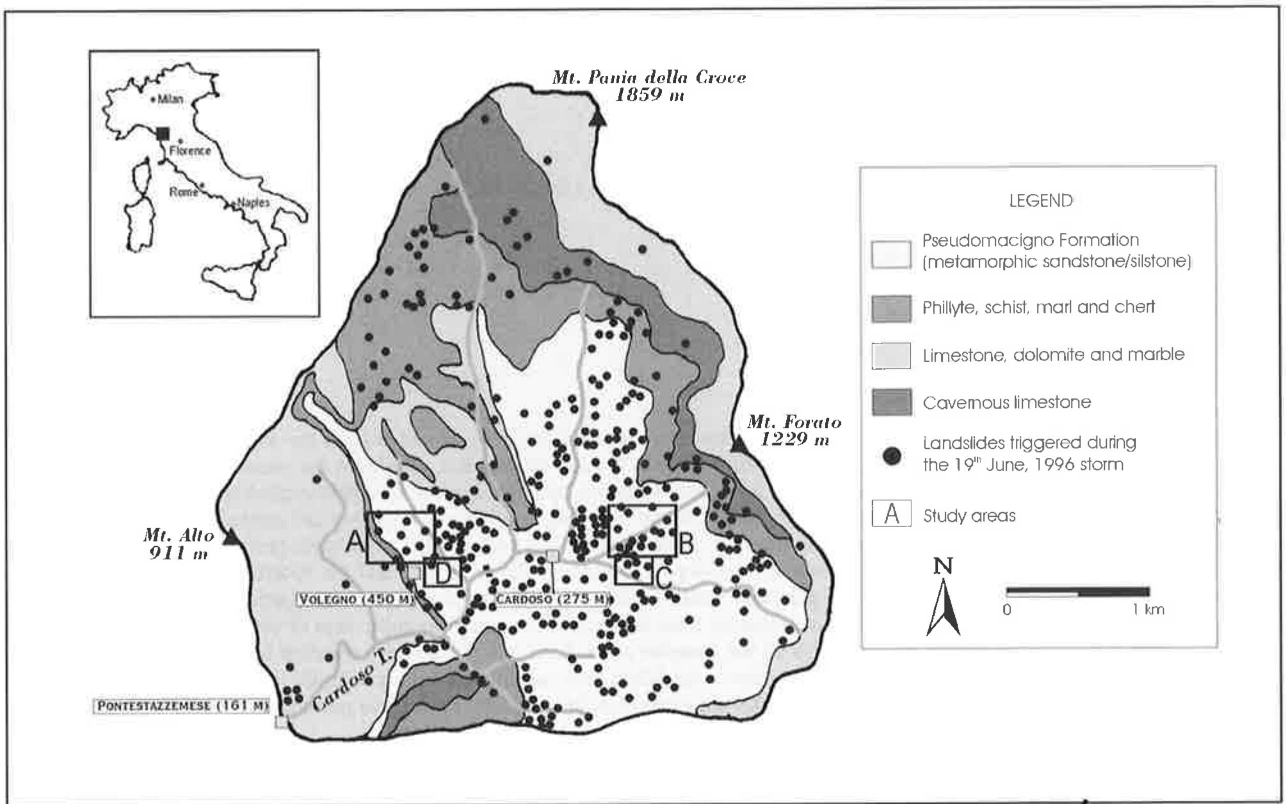

Figure 1. Lithologic sketch map and location of survey areas in the Cardoso Torrent basin.

The slopes modelled in non-calcareous rocks (schistose-phylladic and metarenaceous formations) are usually less steep, above all in the intermediate altitudes (the steepness remain however fairly high, often varying from 30 to 40 degrees). An increase in gradient is manifested moreover in the lower edges of the slopes, a phenomenon presumably attributable to the accentuation of the erosive processes, resulting from the recent uplift that involved the Apuan metamorphic nucleus. The slopes characterized by predominantly schistose-phylladic and metarenaceous formations, reaching heights of about 800-900 metres, present an almost continuous, pedogenized colluvial covering. However, due to the considerable steepness, this cover is of fairly modest thickness, between a few decimetres and two metres (rarely more). On these slopes there is mainly a high-trunk vegetation of high density (prevalently chestnut), often in a state of abandonment; near the villages there might be areas used for agriculture, while grazing lands are found at higher altitudes. In other rare cases, the covering is represented by dormant landslides, which in general can be considered to belong to the rotational or translational slide typology.

3 METHODOLOGY OF SURVEY

Detailed studies, aimed to analyse the landslide areas of the June 19, 1996 rainfall event in the basin of the Cardoso Torrent and in some neighbouring basins (D'Amato Avanzi et al. 2000, 2002), highlighted a series of geological and geomorphological characteristics recurring in the slopes involved. The slope-type most affected by soil slips presents characteristics that can be summarised thus: a) colluvial cover 0.5-2 m thick; b) impermeable or semi-permeable bedrock, in particular Pseudomacigno Fm.; c) concave morphology; d) rectilinear profile; e) 31-45° gradient; f) chestnut wood covering.

Since not all the slopes with such characteristics were involved in landslide movements, it was considered opportune to examine other factors that might have exercised a not secondary role in the stability of the slopes. Hence a geognostic survey was carried out to obtain the main geotechnical and hydrogeological parameters of the colluvial covers of the Pseudomacigno Fm., both in the slopes affected by landslides and those remaining stable. During the geognostic surveys, *in situ* tests were carried out and samples of the terrain were taken, subsequently analysed at the Laboratory of Applied Geology and Geotechnics of the Earth Sciences Department of Pisa. The surveys carried out are summarised as follows:

Field surveys
- Penetrometer tests
- Permeability tests

Laboratory analyses
- Determination of the grain size curve
- Determination of the consistency limits (Atterberg limits)

As already mentioned, the choice of sites to be studied was based on previous studies carried out in the area (D'Amato Avanzi et al. 2000, 2002), the aim of which was the identification and characterization of the slope-types in which the shallow landslides of June 19 1996 were localised with the greatest frequency. The choice of zones on which the research was applied fell therefore on zone A (W of Cardoso) and on zone B (E of Cardoso), considered representative of the most typical situations of landslide susceptibility. Other geognostic tests were carried out on some isolated slopes (zone C and D) (Fig. 1).

Zone A is characterised by the outcrop of the Pseudomacigno Fm., generally dipping downslope. The area is mostly covered by a thin, pedogenized, colluvial material, of variable thickness (from a few decimetres to two metres), greater in the slopes with a concave morphology. On the occasion of the storm of 1996, 8 shallow landslides were localised in this area. The main one involved a surface of about 8,000 m^2 and a volume of about 15,000 m^3 of colluvial material. It occurred in a hollow on a bedrock dipping downslope, with an inclination similar to that of the slope (35-40°). Because of such characteristics, the zone was considered particularly suitable for acquiring the first representative data regarding the cover terrain of the areas subject to landslides; thus, various surveys were carried out on this area. Since the slope on which the landslide occurred was denuded, the tests were carried out right at the edges of the landslide area. This procedure was also followed for all the other slopes affected by landslides.

In zone B the Pseudomacigno Fm. outcrops again, but on the whole dipping upslope; the thickness of the cover presents characteristics analogous to what was already observed for Area A. In this zone 6 main soil slips were triggered, almost all in the elementary concavities of slopes with gradients of about 35-40°.

Further surveys were carried out in another zone east of Cardoso (zone C), near some areas where landslides occurred, and in Volegno (zone D), around a slope that was not mobilized on June 19 1996. The overall detail of the surveys carried out in the basin of the Cardoso Torrent during the various phases of the research is illustrated in Table 1.

Table 1. Tests carried out in the Cardoso area.

Survey	N° tests
Penetrometer tests	19
Permeability tests	15
Samples taken	17

4 FIELD SURVEYS

4.1 *Penetrometer tests*

The penetration tests were carried out using a light static-dynamic self-anchoring with hydrostatic cell "Dinastar TP311" penetrometer (25 kN force and mantle-cone type point), produced by Tecnotest, in use at the Laboratory of Applied Geology and Geotechnics of the Department. The penetration method used was the static one, which provides more information on the typology of the terrain analysed.

During the series of *in situ* surveys carried out in the study area, 19 penetration tests were done, over 8 slopes involved in the landslides of June 19 1996 and 4 on slopes that remained stable. Further surveys are still in progress; from the preliminary data that have emerged, the materials seem in any case to be prevalently granular, with a verifiable angle of friction of around 28-33°. These characteristics are also confirmed in the grain size analyses of the samples collected (par. 5.1).

Some interesting conclusions can be drawn from the analysis of the thickness of the slopes covers and of the presence of a portion altered/fractured of bedrock.

As mentioned above, the covers of the areas studied usually have a thickness of a few metres; moreover, it was observed that the 8 slopes involved in landslides on the occasion of the event of June 1996, on which surveys have been carried out, generally presented covers 0.5-2 m thick, with only one case above this (average of the slopes: 1.5 m). The 4 study slopes remaining stable during the downpour, on the other hand, had covers 1.8- 3.4 m thick (average of the slopes: 2.6 m).

Another datum emerging from the penetration tests regards the presence of a very altered and/or fractured portion of the bedrock, which in the cases examined is represented by the Pseudomacigno Fm. In the slopes affected by landslides the presence of an altered/fractured portion of the bedrock 10-20 cm thick emerged, while for those not affected by sliding such a level was usually more than 20 cm thick. Some excavations and local sections confirmed this fact.

4.2 *Permeability tests*

During the penetration tests carried out the possible presence of water table was investigated, that had never been observed even on the day immediately following days of rain.

In order to assess the permeability of the cover materials, absorption well tests were carried out. Working with shallow wells of small dimensions local information can obviously be obtained which might not however represent perfectly the characteristics of the acquifer as a whole. Taking this into account, such information is in any case useful because it provides a general indication of permeability, above all if compared with the other analyses carried out on the same materials (grain size analyses, consistency limits, etc.). Moreover, the value of the well test is also confirmed by the modest thickness of the colluvial covers of the area.

According to the regulations of the Italian Geotechnical Association (A.G.I.), well tests can be carried out in the presence of prevalently granular terrains ($k > 10^{-6}$ m/s), with the depth of the water table seven times the depth of the well and with a hole width about 10-15 times the maximum diameter of the granules of the terrain (Viggiani 1974; A.G.I 1977). These conditions were satisfied during the execution of the tests carried out in this study. The tests were performed in unsaturated soils.

In the cases examined the variable load test was used, by means of wells with a square base (30-40 cm sides) and vertical walls, without lining. The tests were made by introducing water in the well and measuring the drawdown-time relationship.

In the areas studied a total of 15 permeability tests were carried out. The results obtained are shown in Table 2 (slopes involved in mass movements), Table 3 (slopes not involved in landsliding) and in Figure 2.

Table 2. Values of the permeability coefficient k of colluvial material of slopes affected by soil slips.

Zone	Test	k (m/s)	Zone	Test	k (m/s)
A	M1	2.8×10^{-5}	B	M10	2.4×10^{-5}
A	M2	1.1×10^{-5}	B	M13	1.8×10^{-5}
B	M7	1.4×10^{-5}	C	M14	4.6×10^{-5}
B	M8	7.4×10^{-6}	A	M17	5.1×10^{-6}
C	M9	4.3×10^{-5}	A	M19	4.3×10^{-5}

Average: $k = 2.1 \times 10^{-5}$ m/s

Table 3. Values of the permeability coefficient k of colluvial material of slopes not affected by soil slips.

Zone	Test	k (m/s)	Zone	Test	k (m/s)
A	M3	2.7×10^{-5}	A	M6	3.6×10^{-5}
A	M4	3.8×10^{-5}	A	M18	3.6×10^{-5}
A	M5	1.3×10^{-5}			

Average: $k = 3.0 \times 10^{-5}$ m/s

Most of the values obtained show a permeability coefficient k of the order of 10^{-5} m/s, which corresponds according to some authors (Castany 1982; Celico 1986) to a low degree of permeability, while others (Colombo, Colleselli 1996; Scesi, Papini 1997) attribute a medium-low degree to this value. Only in two cases the permeability obtained was lower, of the order of 10^{-6} m/s. Distinguishing the results for the zones affected by the landslides and for those that remained stable on the occasion of the floods of June 19, 1996 (Tables 2-3 and Fig. 2), a slightly greater permeability can, in general, be observed for the colluvial covers of the slopes remained stable (the average value is 3.0×10^{-5} m/s, as against 2.1×10^{-5} m/s of the areas involved in landslide).

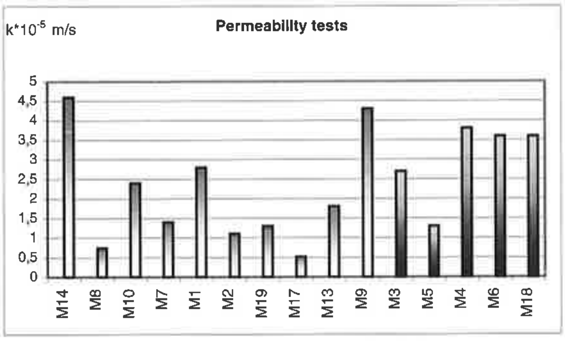

Figure 2. Results of the permeability tests: in light grey are represented the tests carried out in the proximity of the landslide areas; in dark grey those obtained on slopes not affected by landslides.

5 LABORATORY ANALYSIS

For the determination of the physical characteristics of the colluvial material some laboratory analyses were also carried out, above all with the aim of identifying the particle size classes and to determine the plasticity field of the samples collected; these data were also used for the classification of the materials.

The samples were usually collected manually, using small samplers, 19.7 cm long and with a diameter of 4.2 cm. In consideration of the dimensions of the samplers and the technique of fixing (beating), the material collected in situ was not assumed to be undisturbed, but treated as being in every respect disturbed.

The samples were taken in the proximity of the penetration tests and the permeability tests carried out.

5.1 *Grain size analyses*

According to Cruden, Varnes (1996), the type of material is referable to the category of "debris" (the fraction greater than 2 mm ranges from 20 to 80%); only in some cases it is represented by "earth" (the fraction less than 2 mm is over 80%).

The grain size analysis was carried out according to the A.G.I. (Italian Geotechnics Association) recommendations on the geotechnical laboratory tests (A.G.I 1994).

The analyses of the samples were carried out primarily in a damp state, then, after drying, siftings were carried out, with a lower sift mesh diameter of 0.045 mm (sift n° 325 of the ASTM series). The finest fraction, i.e. that passing through sift n° 200 (0.075 mm), was analysed by means of the procedure of sedimentation of a watery suspension of the particles being studied.

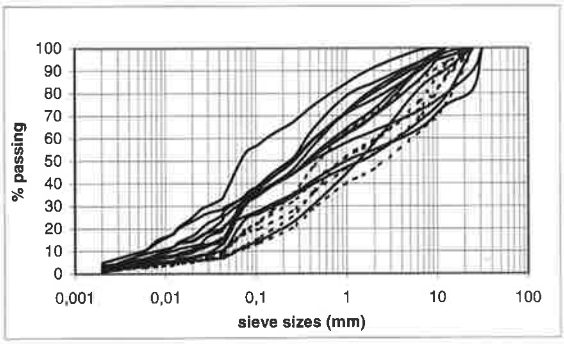

Figure 3. Grain size envelope; the curves of the samples collected on slopes undergoing landslides are represented in continuous line; those of the samples collected in areas not affected by landslides in dotted lines.

Figure 3 shows the total grain size distribution obtained for the study areas, while Figure 4 shows the triangular diagram of the total grain size composition of the samples.

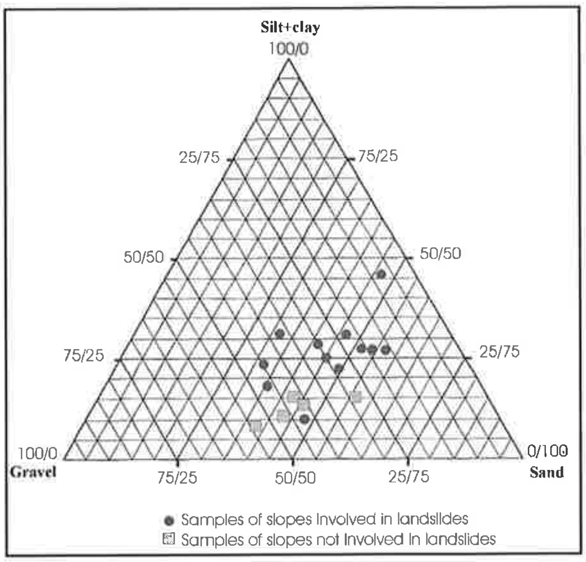

Figure 4. Triangular diagram of the grain size composition of the samples; in consideration of the low clay content (< 5%), the percentage of fines (silt and clay) was incorporated.

According to the USCS classification the samples usually fall into the SM class; both from the grain size arrangement and from the triangular diagram a substantial heterogeneity of the materials can in any case be perceived (the uniformity coefficient, the ratio of the 60% particle size to the 10% particle size, D60/D10, is generally somewhat above 20).

From the comparison between the grain size curves of samples collected in landslide areas and those of samples collected in slopes not affected by landslides, a finer granulometry emerges for the slopes destabilized during the floods of June 1996 (see Figs. 3-4).

5.2 *Atterberg limits*

In order to identify the plasticity characteristics of the samples collected, the tests for the determination of the consistency or Atterberg limits were carried out.

The tests to identify the Atterberg limits were executed on the passing of sift n° 40 (diameter of 0.425 mm) and were carried out according to the CNR-UNI 10014 regulation.

Initially some samples of the area corresponding to the main landslide situated in zone A were taken and compared with samples collected in adjacent slopes, not affected by shallow landslides during the rainfall of June 1996. The results are shown in the graph of Figure 5, which shows the distribution of the liquid limit (WL) – plasticity index (IP) pairs for the samples analysed (Casagrande Plasticity Chart).

As can be seen from the graph, most of the samples fall within the field of medium-low plasticity, inorganic silt; moreover, there is a certain visible difference between the liquid limit values for the samples collected near the landslide and those collected in slopes that remained stable, for a substantially similar thickness of debris cover; in particular, a higher value of WL for the samples collected on the slopes not affected by landslide phenomena emerged.

Subsequently, all 17 samples collected were included in the plasticity chart, again distinguishing those collected in the landslide areas and those collected in zones not affected by landslides. The results are shown in the graph of Figure 6.

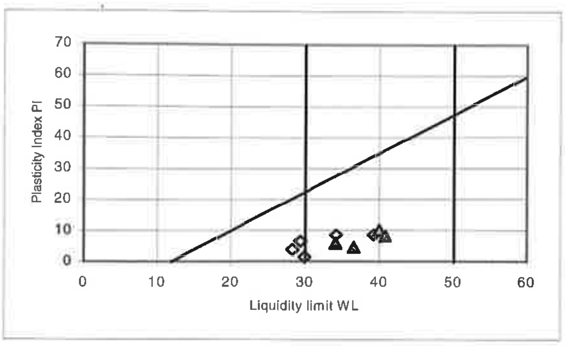

Figure 5. Plasticity Chart of a portion of zone A. The samples collected in the landslide area are represented with squares; the triangles represent the samples collected on the adjacent slopes not affected by slips.

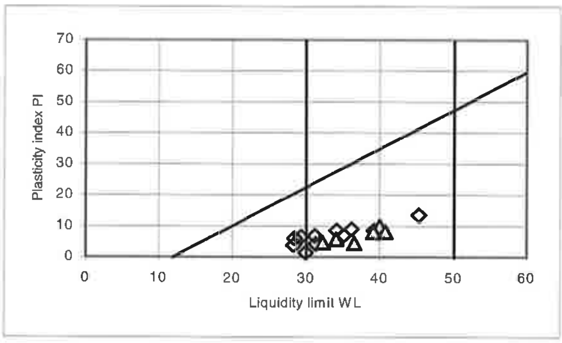

Figure 6: Plasticity Chart of all the samples collected. The samples of landslide areas are represented with squares; the triangles refer to the samples collected on slopes not involved in landslides.

Although the difference in liquid limit between the samples collected in the landslide areas and those collected on the slopes not involved in landslides is less marked, a certain distinction seems however to be maintained, the plasticity index being substantially equal.

6 CONCLUSIONS

The preliminary geotechnical surveys carried out on the cover materials of the Pseudomacigno Fm. in the area of Cardoso (southern Apuan Alps) highlighted some interesting aspects regarding the characteristics of the slopes involved in the landslide movements on the occasion of the hydrogeological catastrophe of June 19 1996.

From the penetration tests carried out it emerged that the slope destabilized during the event seems to have a thinner debris cover than the slopes not involved in landslide movements and a bedrock with a modest altered and/or fractured portion, which was, however, greater for the slopes remaining stable. The presence of a thick layer of altered/fractured bedrock might have favoured better drainage of the cover terrains, with a limitation of the processes of formation of pore water pressure phenomena. The permeability tests seem moreover to highlight a lesser permeability of the covers of the destabilized slopes.

The laboratory analyses carried out showed a finer granulometry for the covers of the slopes involved in landslide movements than those remained stable, and a lower liquid limit (WL).

All the information acquired requires further study with other surveys, some of which are already in progress; moreover, the possibility of also collecting undisturbed samples will make it possible to define more precisely the parameters of shear resistance of the cover terrains, at present obtainable only from indirect tests, and to verify the permeability.

In order to quantify also the piezometric response of such covers to rainfall events, two monitoring stations were set up recently on similar slopes to those in which the soil slips occurred, equipped with pluviometer, piezometer and thermometer, with the real time recording of data and the possibility of remote access (D'Amato Avanzi et al., in press)

The results obtained, if confirmed by subsequent surveys, will contribute significantly to the definition of landslide hazard for the area of Upper Versilia, particularly exposed to intense rainfall events.

7 ACKNOWLEDGEMENTS

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