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Stability analysis of landslides occurred close to a marl and limestone quarry

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ABSTRACT: Since the time of the Romans the Euganean Hills have been the site of intense quarrying activity. From the Euganean quarries trachytes and rhyolites in addition to limestones and marls for cement and lime have been extracted. The Cucuzzola quarry is one of the few still active marl and limestone quarries for cement. In this area, due to quarrying of the above materials a landslide involving the detrital sheet occured and partially involved the agricultural soils above the cut face over an extension of about 100 meters. This study was conducted with the aim of defining exactly the unstable area and outlining other contingent connections with quarrying operations.

1 THE GEOLOGY OF THE EUGANEAN HILLS

The oldest outcropping sedimentary rocks in Euganean Hills (fig.1) belong to the Upper Jurassic (Piccoli et al., 1975) and are represented by the Rosso Ammonitico, nodular limestone followed by the Biancone formation (Upper Jurassic-Upper Cretaceous p.p.) made from closely stratified hard limestones. The top of such a formation consists of alternating limestones and thin clayey layers. Then there is the Scaglia Rossa (Upper Cretaceous-Lower Eocene p.p.), a closely stratified limestone. The series ends with the Marne Euganee formation (Lower Eocene p.p.-Lower Oligocene) represented by clayey limestones and marls.

In the period going from the Eocene to the Lower Oligocene there was an intense eruptive activity in the zone which had a basic character with a flood of basaltic lavas in the Upper Eocene. The elements are wider and go from rhyolites to latites and even to basalts in the Lower Oligocene.

As far as that concerning the tectonic structure of the Euganean Hills, the zone involves a close faults network with chief trends, strikes and directions running NNW-SSE and NE-SW.

From the geomorphological point of view, the difference between sedimentary rocks and igneous ones influences the landscape of Euganean area, where steep eruptive hills contrast with the gentle slopes of the sedimentary formations.

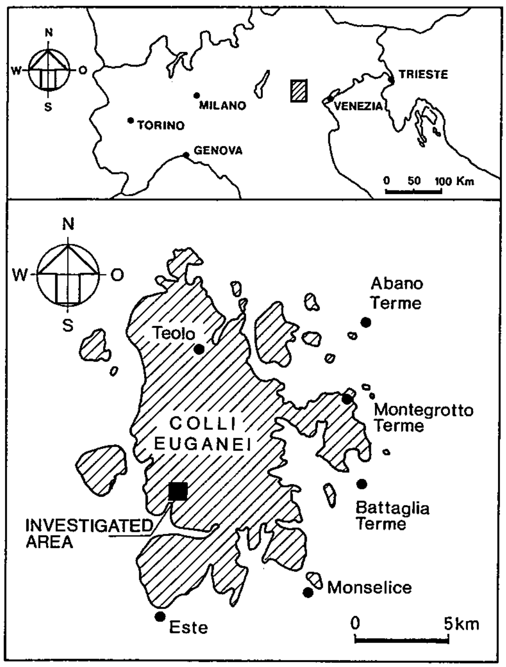

Fig.1 Location of the site

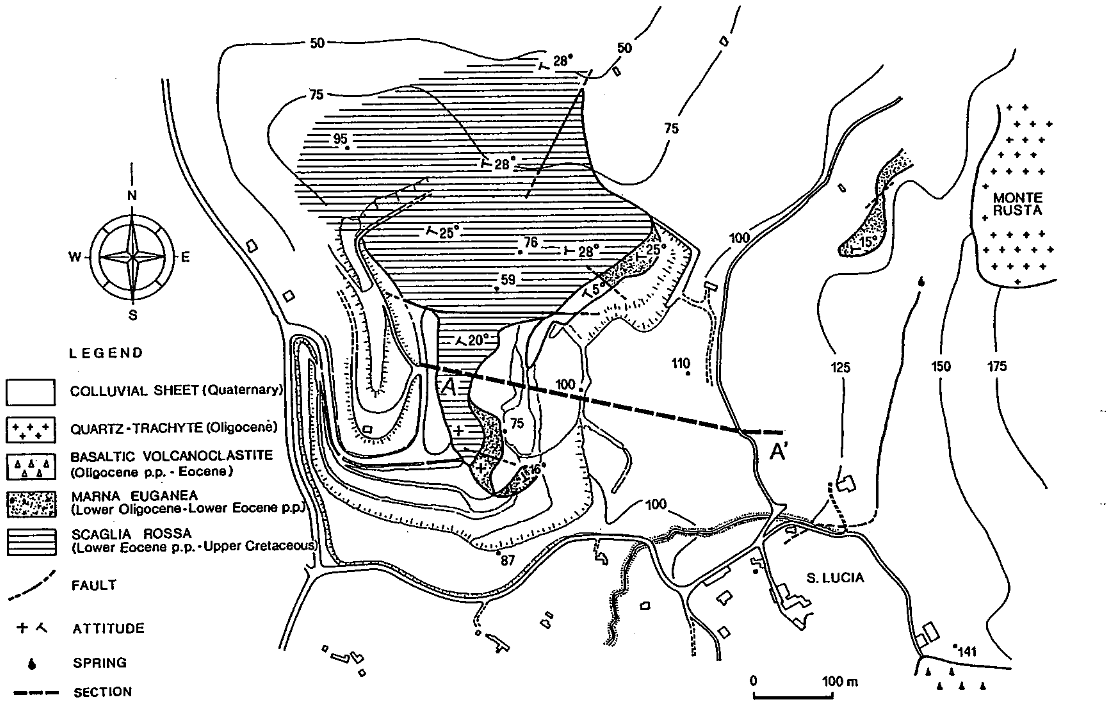

Fig.2 Geological map of the investigated area

2 GEOLOGY, GEOMORPHOLOGY, HYDROLOGY OF THE INVESTIGATED SITE

The investigated piedmont area (fig.2) is built up on an extention of about 0.6 km^2 and on elevations ranging between 40 and 140 m. The sedimentary formations are represented by the Scaglia Rossa and the Marne Euganee, associated with Quaternary overburden soils. The igneous formations are represented by eocenic basaltic volcanoclastites, trachyte lavas and alkaline quartz-trachytes of the Lower Oligocene age. The Scaglia Rossa extensively outcrops in the vicinity of the quarry area and presents a thickness of around 50 m.

The attitude is more or less constant around a NNE-SSW direction with a dip direction ESE of 25÷30°. At the top the Scaglia Rossa varies in composition tending toward limestone-marly elements. At this point the attitude is around a NE-SW direction with a less accentuated SE dip direction of 15÷20°.

Limited to the extreme southeast area of the geological map, weathered and locally clayerfied eocenic basaltic volcano-clastites are outcropping. The Rusta Mount is built up by eruptive alcaline quartz-trachytes of the Oligocene age. The rock shows typical columnar gashes. The trachytic body of Rusta Mount and the Marne Euganee are evidently discordant.

The Quaternary deposits are principally made up of detrital materials and alluvial deposits. The slopes of Rusta Mount are covered by coarse trachytic sheet mixed with finer elements. At lower levels beginning at 125÷150 m, where slopes are gentler, such coarse deposits are substituted by mostly clayey soils with a skeleton made up of abundant trachytic elements more or less weathered and angular, with dimensions varying from a few centimeters to several decimeters. The thickness of such a detrital sheet reaches even 25 and more meters (fig.3).

The area is characterized by a somewhat poor ground water flow. Only two surface waterways exist which turn out to be generally dry, even following intense long rainfalls. Furthermore a series of works (ditches, cuts, drain wells), for capturing and removing ground water from cultivated fields, convoy water to the two above-mentioned waterways and then toward uncultivated zones.

The existence of a poor underground

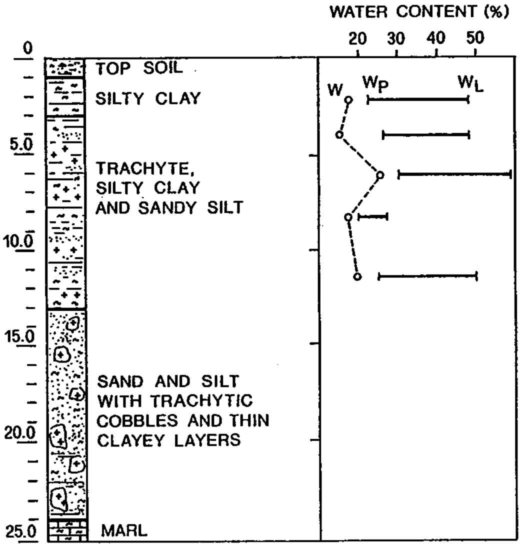

Fig.3 Soil profile with plasticity characteristics

water circulation within the shallow detrital blanket was located. The aquifer layer bed is made up of Marne Euganee which can be considered practically impermeable because of their high clayey component. The quarry area acts as a drainage of the ground water because of its depressed location.

3 ANTHROPIC WORKS AND SLIDING MOVEMENTS

Anthropic works (quarries, cultivations, terracings) have noticeably transformed the morphology of the area characterized by gentle slopes on sedimentary soils contrasting with the sharp acclivities of trachyte reliefs.

Field observations allowed to point out the existence of small movements occuring still now. The imperfect alignment of some vine rows, set up parallel to the lay of the isoipses, shows the existence of slow surface flows due to creep phenomena. Such disarrangements are more evident in the more depressed zones, where there is stagnant water. This is the case of the superficial landslide in course along the west slopes of Rusta Mount: the zone of detachment at an elevation of about 110 m is recognizable through the remolding of the clay and the tilting of the vine rows with typical swellings and depressions as far as a depth of 85÷90 m.

Furthermore rifts and steps, ranging from some tens of centimeters to one meter and over of throw, were found close to the spring. The landslide occuring in the area of the Cucuzzola quarry has exclusively involved the detrital sheet for a presumed thickness of about 20 m (fig.4). The sheet has composed of trachytic detritus, having dimensions varying from a few centimeters to a meter and over, and is immersed in an abundant clayey-silty matrix. This detrital accumulation probably is an old landslide detached from the slopes of Rusta Mount in the old Quaternary. (Piccoli et al., 1975).

The main scarp of the landslide is steep and characterized by a maximum dislevel of about 10 m. At the top there are several cracks. In the landslide there are some secondary slopes which are subparallel to the main scarp and transversal cracks. These are more evident near the fine marly soils remolded by the movement

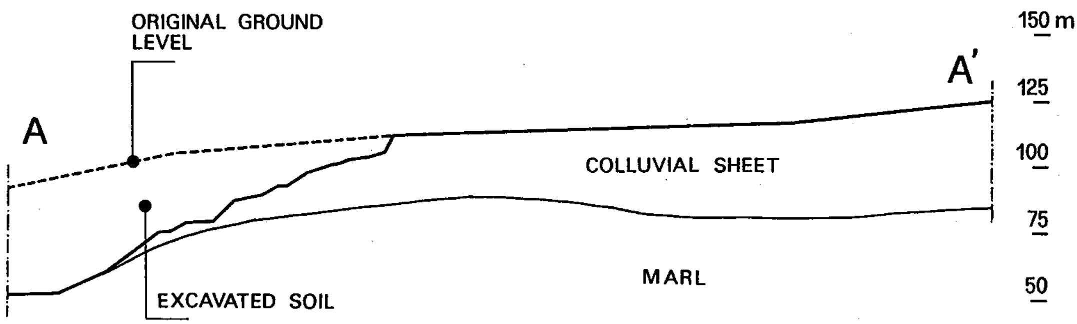

Fig.4 Longitudinal section of the Cucuzzola landslide

and soaked with water. The marly substratum was not completely involved, but abrasion and removal of material developed along its roof.

The coarse and fine mixed material saturated with water ran over the marls and then accumulated at the foot of the slope for a width of about 70 m. A part of the slip surface was certainly localized at the altitude varying from 75 to 85 m. The sliding occured at the marl roof close to a clayey-marly thin layer, acting as a lubricant in conjunction with water infiltrations. The slip surface immerges toward S 40° W with an angle of dip of 22°.

4 SHEAR STRENGTH OF SOILS

Some boreholes, drilled as far as a depth of 32 m from the ground level, were carried out: some undisturbed samples were taken from the detrital sheet within the unstable volume.

Soil mostly is a silty clay with lithic elements having various sizes. Clay fraction ranges from 10 to 25%, plasticity index between 7 and 29%, and unit volume weight between 20.1 to 20.6 kN/m^3.

C.I.U. triaxial compression tests with pore pressure measurement, performed with both ordinary and multistage procedures, were carried out on colluvial specimens of gravelly-silty clay.

The multistage tests were carried out on two different specimens, using one triple-stage compression and one double-stage compression at consolidation stresses ranging from 50 to 300 kPa. It was used the Kondner's hyperbolic criterion (1963) to define the failure condition during the first stages of the tests.

Moreover some ring shear tests were carried out on annular cohesive specimens using the Bromhead's equipment, in order to completely determine the strength of the sheet soils. Peak and residual strength angles range between 25÷34° and 20÷23° respectively. In fig.5 the experimental trends of peak and residual strength angles are summarized.

Since translational movements have been acting for some time, the strength mobilized along the sliding surface should be close to the residual values, except in those zones, located just above the quarry excavation, where falls are occuring.

5 STABILITY ANALYSIS

The variations of pore water level within the slope were recorded for six months by means of five Casagrande piezometers placed inside the boreholes at different depths (tab.1).

Table 1

Location	depth from the ground level (meter)
Cinto Euganeo	7.50
Cinto Euganeo	19.10
Ravarotto House	10.05
Gallo Farm	8.90
Gallo House	15.70

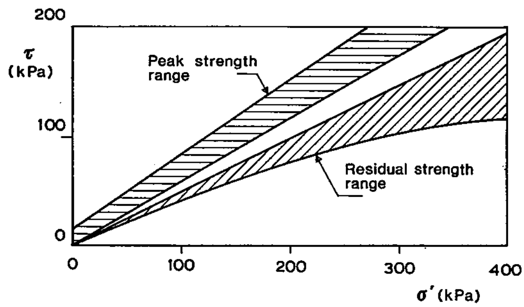

Fig.5 Range of peak and residual shear strengths

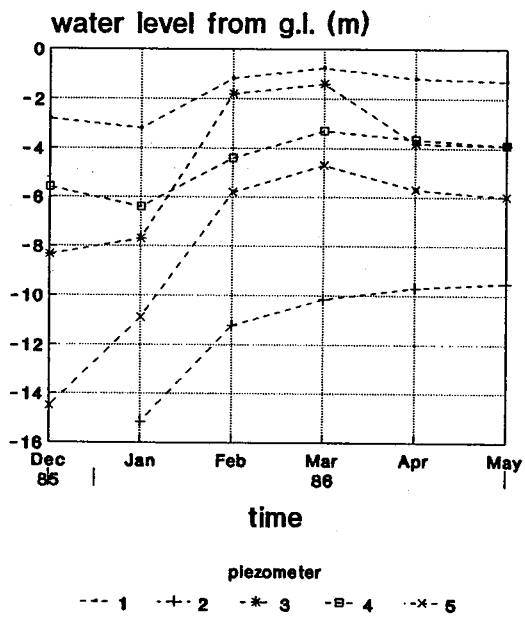

Fig.6 Pore water pressures recorded by means of piezometers

The main aim of this type of measurement was to examine the regime of pore water pressure at levels where the slip surface could exist. Fig.6 shows some significant values of pore water pressure recorded in the examined period of time. Minimum values refer to February-March, while maximum values were recorded in December-January. The seasonal variation of pore water pressures has varied from 2.5 to 10 m, depending on the piezometer location. The saturation surface lifted itself in the winter months all over the zone. In particular, in correspondance with an elevation of 125 m, it rose to 1 m from the ground level. The saturation surface drew down moving toward the front of the excavation. In the section shown in fig.4 it can be observed, apart from the quarry excavation, that the slope is very gentle and somewhere counter-slope. In this zone the substratum can be found at depths ranging from 5 to 17 m from the ground level, with inclination of 13° on the horizontal.

This interface should be the slip surface; deeper failure surfaces cannot be compatible with the nature of involved soils; slallower failure surfaces are safer because the stability index $u/\gamma h$ assumes smaller values.

An unit volume weight of 20.5 kN/m^3, the maximum values of pore water pressure, an inclination of the free surface of 10° on the horizontal, and a residual strength angle of 20° were assumed in the stability analysis. This last assumption derives from the fact that old as well as recent morphological evidences exist; they show that in the investigated site previous landslides and movements of the sheet, due to creep phenomena, have occured.

Slope stability was separately analysed in two different zones, the first (then called zone 1) is close to the front of the excavation, the other (zone 2) at the altitude between 115 and 130 m at S.Lucia.

The zone 1 mostly presents rotational movements which tend progressively to extend upwardly until reaching an equilibrated condition compatible with the shear strength properties of the sheet formation. The slip movement mobilizes undrained strengths, because of its high rate of displacement, and occures along the interface between the colluvial sheet and the marl substratum, at a depth of about 25 m.

Average shear strength τ mobilized along the slip surface can be derived from the following equation (Taylor, 1948):

$$\tau = H \times \gamma \times m \qquad (1)$$

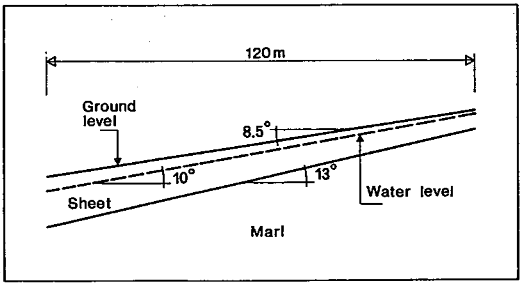

Fig.7 Geometrical parameters used in the stability analysis of the zone 2

where m is the stability number ranging from 0.12 to 0.14 for slope angles of 25÷35°. Then τ is equal to:

$$\tau = 25 \times 20.5 \times (0.12 \div 0.14) = 62 \div 72 \text{ kPa}$$

corresponding to a limit condition. In a safety condition the sheet should be assume an inclination on the horizontal capable to mobilize a shear strength not higher than the following:

$$\tau_{amm} = \tau/F.S. = 62 \div 72/1.3 = 48 \div 55 \text{ kPa} \qquad (2)$$

such a shear strength corresponds to the following stability numbers:

$$m = \tau/(H \times \gamma) = (48 \div 55)/(25 \times 20.5) = 0.09 \div 0.11$$

and to slope angles of 17÷23°.

The instability phenomenon, involving the zone 2, is extremely complex, because of several slow translational movements have been occuring for some time within the sheet. These movements produce a gradual decrease of the shear strength of the involved soils, from peak to residual values. Instability is favoured by high pore water pressures which reduce soil shear strength.

Considering a limited part of slope (fig.7), 120 m long and from 5 to 17 m deep, the factor of safety FS can be so extimated:

$$FS = \frac{(W - U) \times \cos\beta \times \tan \phi'_r}{(W \times \text{sen}\beta)} \qquad (3)$$

where the force produced by water action is:

$$U = 0.5 \times (u_b - u_a) \times L$$

W is the weight of soil volume, u_a e u_b are the pore water pressures at the top, ß is the inclination of marl-sheet interface, ϕ'_r is the residual shear strength angle.

The following values are so obtained:

$$W = 0.5 \times (17\ m+5\ m) \times 120\ m \times 20.5\ kN/mc = 27060\ kN/m$$

$$U = (100+40) \times 0.5 \times 120 = 8400\ kN/m$$

$$FS = \frac{(27060-8400) \times \cos 13° \times tg20°}{27060 \times sen13°} = 1.1$$

The factor of safety shows how the limit condition is close to the present condition of the slope; in fact if pore water pressures still increase, failure can occur.

6 CONCLUSIONS

The aim of this study was to determine possible relationships between quarrying activity and the instability phenomena occured in the area close to the Cucuzzola quarry.

The investigation allowed to establish that:
- rotational movements occured at the front of the excavation are due to quarrying cuts which have inclinations not allowable with the shear strength of the involved soils;
- many translational movements have been occuring for some time in an area just above the quarry; some of them already occured in geological time;
- they are due to scanty residual strengths and creep phenomena of involved soils and to high values of pore water pressures;
- the marl substratum, on which the sheet seems to be sliding, is opposite-slope just above the quarry;
- due to anthropic terracings water cannot flow superficially and so filters within the detrital sheet increasing pore pressures and decreasing soil strength.
- limit condition is close to the present condition of the slope; if pore pressures increase, failure can occur.

In conclusion it seems that there are no connections between quarrying activity and the situation of general instability of the area situated just above the quarry.

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