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The role of anisotropic permeability on slopes instability conditions

Le rôle de l'anisotropie de perméabilité sur les conditions de la stabilité des pentes

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SYNOPSIS The hydraulic behaviour and the consequent instability processes in a slope, which summarizes the features of similar slopes in Central Italy, have been analysed by successive finite difference numerical models. The physical phenomena in the slope seem to be fully explained by a stratified anisotropic model.

INTRODUCTION

Geotechnical investigations carried out in some flat slopes in Central Italy, affected by mainly translative large landslides and formed of overconsolidated marine clayey deposits, have been shown the hydraulic conditions are characterized by phreatic surfaces always close to the ground surfaces and by an upward pore-pressure gradient in the holes drilled in the lower portion of slopes.

Observed values of neutral pressures result larger than the theoretical ones, the latter referred to the homogeneous and isotropic media.

The preliminary stratigraphic knowledge shows that the slopes exhibit strata dipping nearly coincident with the already moderate topographic gradient. Moreover the slopes have more or less thick colluvial covers, which overlie rather weathered brown-yellowish clays and laminated grey-blue clays.

The aim of the paper is to understand the particular hydrogeological processes which govern the instability phenomena in progress. This has been obtained by means of different numerical models, which have been successively developed.

SLOPE HYDROLOGY

The slope shown in Fig. 1a has been chosen because among all the other similar analysed slopes it has provided many significant hydrogeological data and summarizes the hydraulic features of the above-mentioned slopes.

Soon after the first piezometric surveys, it has been clear the pressure field in the lower portion of slope was particularly high, as it is shown in literature for many natural slopes

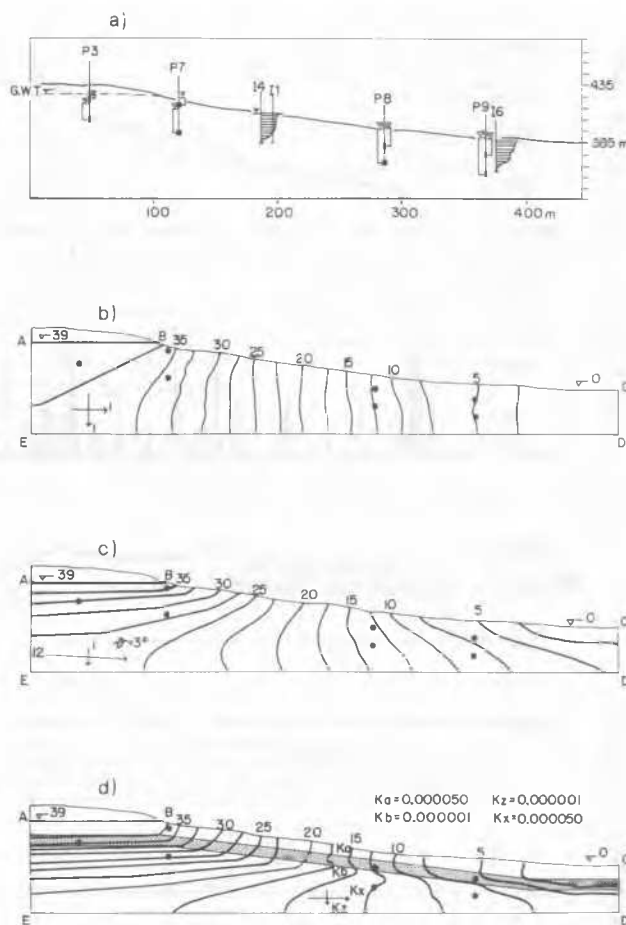


Fig. 1 Analyzed slope: a) hydraulic conditions of slope and geometrical features of landslide; b) hydraulic head pattern for homogeneous and isotropic media; c) hydraulic head pattern for homogeneous and anisotropic media; d) hydraulic head pattern for stratified media.

(La Rochelle et al., 1977; Patton and Hendron, 1974; Skempton and Hutchinson, 1969). Unfortunately the measures in the piezometers showing an upward pore-pressure were not carried out in the first period, which provided extended rainfalls (for over three months).

Afterwards the piezometric levels, measured in the lower portion of this slope, have maintained elevations up to 1 metre from the ground surface (Fig. 1a, 2, 3). Besides the behaviour of the piezometer No. 8, of which the figure 2 represents the qualitative trend of experimental equipotential lines, has constituted the starting point for the complete understanding of physical phenomena.

At last, it can be noticed as extended rainfalls of moderate intensity can strongly

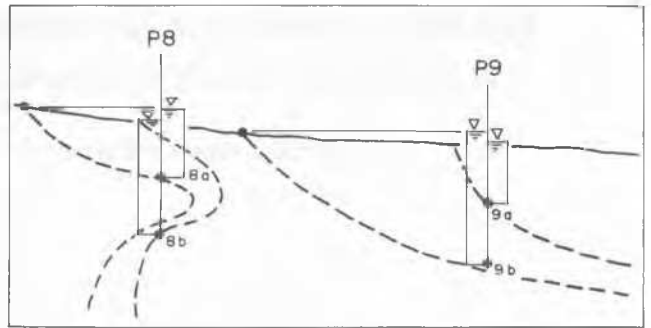


Fig. 2 Hydraulic head pattern in the lower portion of the slope.

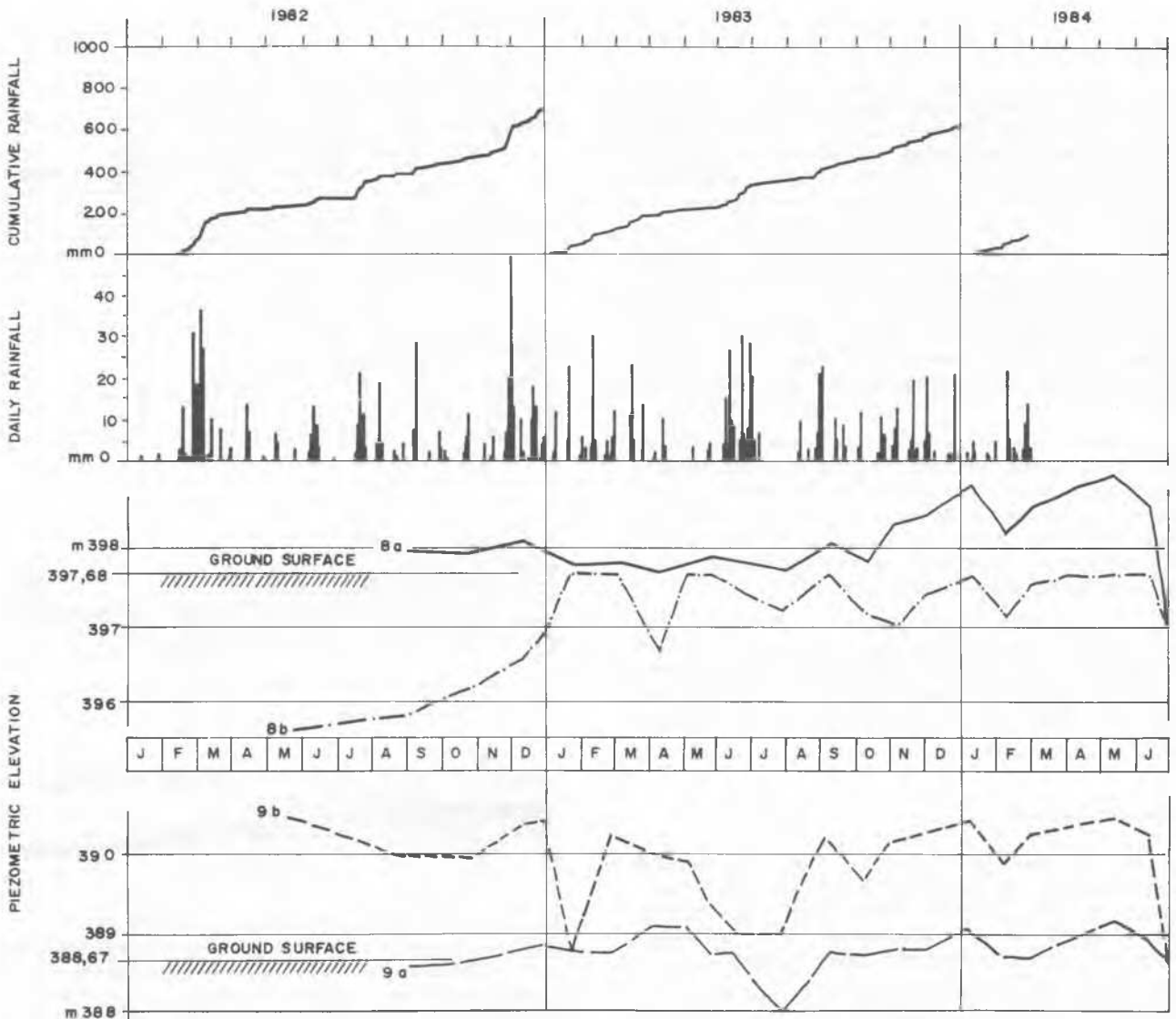


Fig. 3 Relationship between rainfall and piezometric elevation.

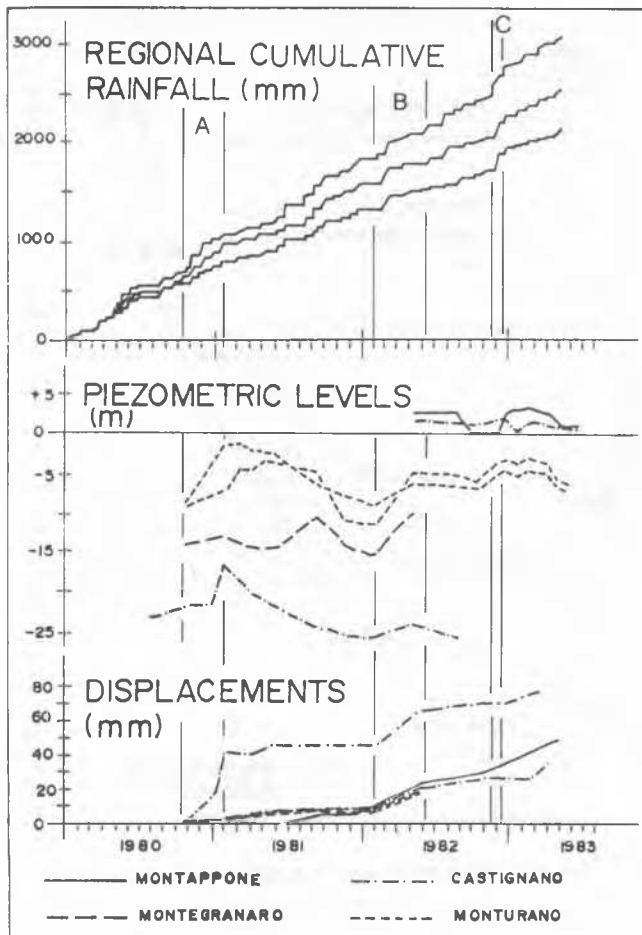


Fig. 4 Relationship among rainfalls, piezometric levels and displacements (from: Tonnetti and Angeli, 1984).

affect the hydraulic conditions and movements of these failed slopes (see zones A and B in Fig. 4), while large rainfall intensities, of relatively short period (see zone C in Fig. 4), do not seem affect significantly the above mentioned hydraulic conditions and movements.

PROGRESS ON THE MODELING TECHNIQUES

Successive finite difference numerical models have been applied to approximate the real hydraulic conditions of the slope shown in Fig. 1a.

The first step was the application of the equation for saturated steady flow through isotropic, homogeneous, rigid porous media, expressed in two dimensions as follows:

$$k \frac{\partial^2 h}{\partial x^2} + k \frac{\partial^2 h}{\partial z^2} = 0 \quad (1)$$

known as Laplace equation; where k is the hydraulic conductivity and h is the hydraulic head. The boundary conditions are (see Fig. 1b):

- on AE, ED and CD contours the constant zero flux conditions have been applied (the contours become flux lines);
- on AB and BC contours a constant head is fixed at the same values of the ground water table elevations.

The simplest central finite-difference model has been applied. The results are by far different from the physical model, as it can be noticed by the hydraulic head pattern in Fig. 1b.

The second step was the application of the equation for saturated steady flow through anisotropic, homogeneous rigid porous media (Angeli, 1983) expressed again in two dimensions as follows:

$$k_x \frac{\partial^2 h}{\partial x^2} + 2k_{xz} \frac{\partial^2 h}{\partial x \partial z} + k_z \frac{\partial^2 h}{\partial z^2} = 0 \quad (2)$$

where k_x , k_z and k_{xz} are the components of the conductivity tensor in the coordinate system x, z .

The application of (2) has been suggested by the observation that the slope is composed of alternating layers of different textures. For this reason, the inhomogeneous slope being equivalent in its behaviour to an homogeneous anisotropic medium (Bear, 1972), can be in this way treated.

The expressions for k_x , k_z and k_{xz} are:

$$k_x = \frac{k_1 + k_2}{2} + \frac{k_1 - k_2}{2} \cos(2\vartheta) \quad (3)$$

$$k_{xz} = -\frac{k_1 - k_2}{2} \sin(2\vartheta) \quad (4)$$

where k_1 and k_2 are the principal conductivity coefficients and ϑ is the angle value of the two different coordinate system (x, z and x_1, z_1).

The hydraulic head pattern in Fig. 1c (with $k_1/k_2 = 12$ and $\vartheta = 3^\circ$) represents the best fit of this model with the physical one. In fact, it is known as in the anisotropic formations the groundwater conditions arise, where the axis of maximum conductivity is nearly parallel to the dip of the slope (Hodge and Freeze, 1977).

In spite of the obtained results, the problem of the physical model, on the whole, was not yet worked out.

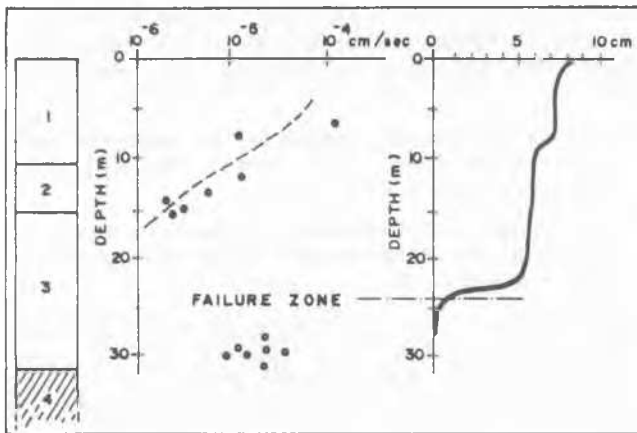


Fig. 5 In situ horizontal hydraulic conductivities trend vs. depth (from: Tonnetti and Angeli, 1984).

In the mean time, in situ permeability tests were performed all over the slopes previously taken into consideration (Tonnetti and Angeli, 1984). The result of these tests summarized in Fig. 5, shows higher values of hydraulic conductivity in the upper strata, lower ones in the middle and again higher in the deepest strata, which are constituted of laminated grey-blue clays exhibiting an high ratio between the maximum and minimum principal conductivities.

The previous result has suggested the application of a stratified model, which utilizes substantially the same above-described equations. Nevertheless it has been necessary to solve many numerical problems chiefly concerning the boundary conditions among the media which exhibit different values of hydraulic conductivities (k_a , k_b , k_x , k_z (cm/s)).

The hydraulic head pattern in Fig. 1d fully explains the physical model. In Fig. 6 the measured and predicted piezometric elevations are summarized.

CONCLUSIONS

- (1) The anisotropic model provides high values of neutral pressures nearly coincident with the measured ones and explains, apart from the analysed slope, the role of anisotropy in promoting instability conditions in the stratified slopes;
- (2) the stratified model fully explains the physical phenomena in the studied slope;
- (3) the stratified model, taking into account the anisotropic characteristics of the basal laminated grey-blue clays, provides

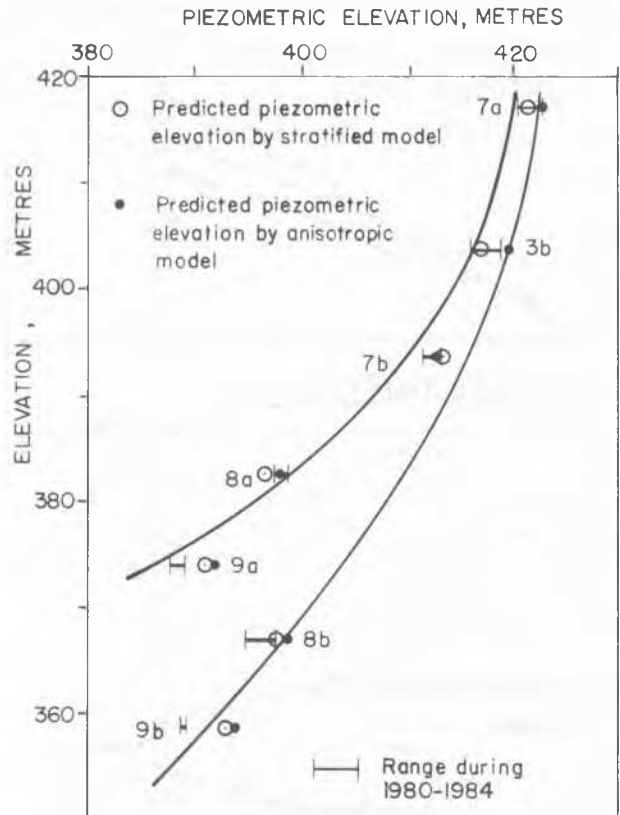


Fig. 6 Measured and predicted piezometric elevation.

also large values of neutral pressures in the lower portion of slope; thus the landslides result active, although the pluviometric conditions are not particularly heavy.

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