Short-Term and Long-Term Stability of Slopes

Stabilité à Court et à Long Terme des Pentes

N.A. TSYTOVICH Prof. D.Sc. (Eng.), Corresponding Member USSR Academy of Scienses;
Z.G. TER-MARTIROSYAN Prof. D. Sc. (Eng.), Kuibyshev Civil Engineering Institute, Moscow, USSR

SYNOPSIS. On the basis of an analysis of laboratory and field investigations, the paper elucidates the essence of the landslide process in the case of cyclic variation of the landslide-initiating factors. It is proposed that the theory of viscoplastic flow be used to describe the process of accumulating plastic deformation in the soils making up landslide slopes.

One of the typical features in the dynamics of the landslide process as it develops in mild slopes composed of clayey soils is their cyclocity, which is due to the variation of a number of landslide-initiating factors with time. Such factors include the intensity of atmospheric precipitation, ground water level, water head in water-bearing strata, etc.

The overwhelming majority of such slopes may be in the stage of steady-state secular creep; they may deform very slowly and rarely go over to a stage of progressive flow and collapse. Engineering structures may be located on such slopes and be in regular use for long periods depending on their sensitivity to non-uniform deformation. Hence, the basic problem is to predict the magnitude of landslide displacement (or the rate of its development) over a given period of time. This amounts to a calculation of the long-term stability of the slope on the basis of limiting deformation. Short-term stability of mild slopes is guaranteed, as a rule, because they are not subject to catastrophic displacements.

Quantitative methods of assessing landslide displacements are still in an early stage of development. This is due, not only to the complex mathematical problems involved, but also to the problem of determining the rheological parameters of the soil in the massif in situ. The method of determining theological properties of soil by loading gives no real idea of its rheological behaviour in a massif where it has been in a stressed state for a long time. The most effective method in this respect is to determine the rheological parameters of the soil in the massif from the results of an analysis of observations on the dynamics of the slope in space and time, i.e.by means of reverse calculations.

At the resent time, the prediction of creep deformation in slopes, when the deformation is due to the stationary gravitational field of stresses and the cyclic variation of an additional stress field, is based on the theory of viscous and viscoplastic flow of a multiple-phase soil medium, as well as on the theory of the propagation of pressure waves in a porous deformable medium (Ter-Martirosyan, 1971; Tsytovich et al, 1977).

According to the second of these theories, the accumulation of plastic deformation in the soil can occur in the case when an additional change in stresses leads to a stress- in excess of the limiting long-term strength of the soil (Fig.1). Such a change may occur either at a change in the pore pressure or upon a change in the external load on the soil (change in head in a water-bearing stratum, construction of a tentative fill or cut, moistening of the upper layers, etc.).

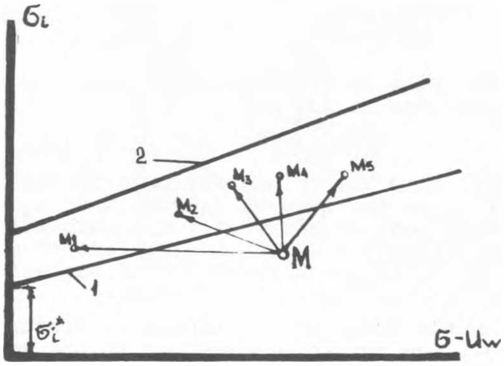

Fig.1. Concerning the mechanism of accumulating plastic deformation in soil: 1-limit of long-term strength or the loading surface; 2- limit of instantaneous strength; M-stressed state at a certain point in the soil massif in a stationary gravitational field; $M_1, M_2, \ldots$-stressed state at the same point after additional action.

Long-term instrumental observations of the dynamics of landslide development.conducted by the authors (Tsytovich,et al,1977), indicate that there is a relationship between the intensity of landslide displacements and changes in the landslide-initiating factors. It can be seen that the most active displacements of surface and depth benchmarks correspond with the period of increased atmospheric precipitation and the rise of the water level in the piezometers. This process is described well by the theory of the propagation of pressure waves in a deformable porous medium (Ter-Martirosyan, 1971).

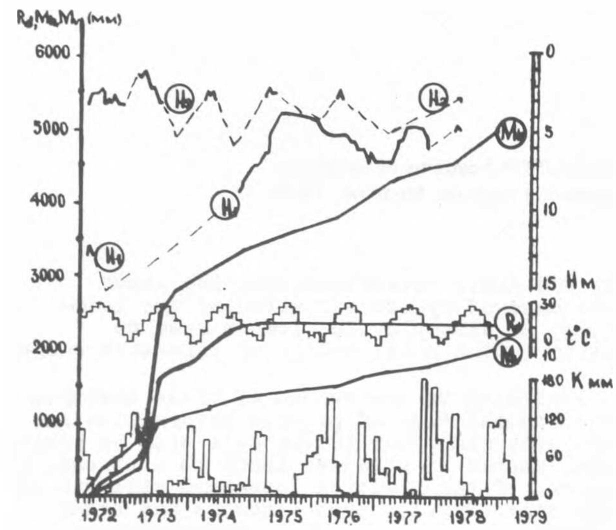

Fig.2. Results of observation of the dynamics of a landslide slope: R_d-displacement of depth benchmarks, $M_{v,h}$-vertical and horyzontal displacement of surface benchmarks, K-amount of atmospheric precipitation, $H_{1,2}$ -groundwater level at various depth in the massif.

For this case, the consolidation equation can be written in the general form

$$\frac{\partial \varepsilon_v}{\partial t} + nm_v \frac{\partial u_v}{\partial t} = \frac{k}{\gamma_w} \nabla^2 u_w , \qquad (1)$$

where ε_v is the volume strain; n is the porosity; u_w is the pore water pressure; m_w is the coefficient of relative compressibility of the pore liquid; k is the coefficient of permeability; γ_w is the unit weight of the water and ∇^2 is the Laplacian operator.

On the basis of the theory of viscoplastic flow, the physical equations of the soil medium can be presented in the form

$$\dot{\varepsilon}_i = \frac{\sigma_i - \sigma_i^*}{\eta_i(\sigma)} ; \quad \varepsilon_v = \frac{\sigma'_v}{m_v} , \qquad (2)$$

where $\dot{\varepsilon}_i$ is the rate of shear deformation; σ_i and σ_i^* are the acting and limiting intensities of the tangential stresses; m_v is the coefficient of volume change of the soil and η_i is the coefficient of viscosity in shear. At $\sigma_i \leqslant \sigma_i^*$ the shape-change deformation is of an elastic nature and can be determined in terms of the modulus of stress relief R, i.e. $\dot{\varepsilon}_i = \dot{\sigma}_i / R$, whereas σ_i^* is determined by a relation of the form of

$$\sigma_i^* = (P_c + \sigma') \tan \Psi , \qquad (3)$$

where P_c is the cohesion pressure; σ' is the average effective stress and tan Ψ is the friction coefficient on an octahedral area. It is obvious that when there are weak soils in the landslide slope, the value of σ_i^* is low and the soils deform at practically negligible shear stresses, i.e. viscous flow occurs.

A common solution of equations (1) and (2), for the case of creep of an inclined water-saturated stratum due to its dead weight, to an external load and the pressure P(t) at the lower boundary that vary with time, has been discussed in works of the authors published in 1971 and 1977.

In determining the distribution law for pressure waves in an inclined stratum, a solution was obtained of the form

$$u_w(z,t) = u_w(0,t) + \frac{z}{H} P(t) + \sum_{n=1,3...}^{\infty} V_n(t) \sin \pi n \frac{z}{H} , \qquad (4)$$

where $V_n(t)$ is a complex function depending upon the way the external load g(t) and the boundary pressure P(t) vary with time and H is the height of the layer.

Upon cyclic variation of g(t) and P(t), a cyclically varying pore pressure is developed in an inclined stratum. This pore pressure causes cyclic changes in the effective stresses which eventually lead to an accumulation of plastic shear deformation in the soil.

A comparison of the results of field and laboratory investigations of soil creep deformation with the theoretical values indicates that they agree to a satisfactory extent.

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