DISCUSSION

Pore pressure changes and the delayed failure of cutting slopes in overconsolidated clay

VAUGHAN, P. R. and WALBANCKE, H. J. (1973). *Géotechnique* **23**, No. 4, 531–539.

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Vaughan and Walbancke discuss the possible mechanisms which can cause delayed failure in cut slopes in overconsolidated fissured clays. Two of the most important of these are pore-pressure equilibration and strain softening; it is the first of these which is their main concern.

The mechanism in the first case is due to the swelling which occurs as load is removed during the process of construction. If the soil is relatively impermeable this gives rise to negative pore-pressures which can take a considerable time to dissipate. The gradual dissipation of these suctions is accompanied by a monotonic decrease in the effective stress and this produces a related drop in the factor of safety of the slope. Thus, the least stable state corresponds to the ultimate steady seepage condition and if the factor of safety for this condition based on the peak strength of the soil is less than unity, then it may not be necessary to consider the second mechanism of failure, i.e. strain softening. Vaughan and Walbancke's results are remarkable for indicating that the loss of stability associated with the dissipation of pore suctions can occupy a time scale comparable with that over which actual failures have been observed to occur.

In commenting on the errors and uncertainties involved in using limiting equilibrium analyses for studying long-term first-time slope failures the Authors observe that 'If the clay has brittle failure characteristics, the peak strength, as measured under uniform strain in the laboratory, cannot be mobilized simultaneously along a field failure surface, along which the strain is non-uniform. Thus progressive failure occurs'. It is worth noting that this can be qualified in relation to the shape of the failure surface which is assumed. If this is circular then a rigid body motion of the soil mass about the centre of the slip circle is possible. This involves uniform strain along the slip surface, so that if the soil were *initially* in a nearly uniform state of strain it would remain so during the slide. In this case non-uniformities in strain will only arise if the soil undergoes significant changes in strain energy during the slide.

The Authors introduce a reduction in drained strength with time, from $\phi'=25°$ to $\phi'=20°$ (with $c'=0$). This is also shown in their Fig. 1. Since a reduction in ϕ' is most probably a consequence of strain softening the soil would appear to be creeping. It would be of interest to know upon what assumptions this creep was based in order that it should give the linear rate of loss of strength τ_f/σ'_n with time shown in Fig. 1.

It is of interest to compare the time rate of loss of shear strength for soil on the slide surface when the mechanism of failure is postulated as either pore-pressure equilibration or strain softening. In general the shear strength of a soil is a function of the effective stress σ', the strain or displacement along the shear plane ϵ, and the strain rate $\dot{\epsilon}$ (if creep effects are to be included) thus

$$\tau = \tau(\sigma', \epsilon, \dot{\epsilon})$$

During a process of pore-pressure equilibration under conditions of constant total stress

$$\left(\frac{d\tau}{dt}\right)_{\epsilon=\text{constant}} = \frac{\partial\tau}{\partial\sigma'}\frac{d\sigma'}{dt} = -\tan\phi'\frac{du}{dt}$$

or

$$\dot{\tau}_{\epsilon=\text{constant}} = -\tan\phi'\dot{u}$$

where dots indicate differentiation with respect to time.

If the pore-pressure is constant so that σ' is constant and loss of strength is due only to strain softening then

$$\left(\frac{d\tau}{dt}\right)_{u=\text{constant}} = \frac{\partial\tau}{\partial\epsilon}\frac{d\epsilon}{dt}+\frac{\partial\tau}{\partial\dot{\epsilon}}\frac{d\dot{\epsilon}}{dt}$$

If the rheological component is small so that the second term on the right hand side may be neglected then

$$\dot{\tau}_{u=\text{constant}} = \frac{\partial\tau}{\partial\epsilon}\dot{\epsilon}$$

Thus the ratio of the rates of loss of strength due to the process of pore-pressure equilibration and strain softening are

$$\frac{\dot{\tau}_{u=\text{constant}}}{\dot{\tau}_{\epsilon=\text{constant}}} = \frac{\partial\tau/\partial\epsilon}{\tan\phi'}\frac{\dot{\epsilon}}{\dot{u}}$$

Vaughan and Walbancke's results suggest that the time to failure by a mechanism of pore-pressure equilibrium might be of the same order as that due to the alternative mechanism of creep softening. When this is the case then the ratio of the rates of loss of strength by the two mechanisms will be determined mainly by the factor $(\partial\tau/\partial\epsilon)/\tan\phi'$. It is thus the gradient of the τ in σ', ϵ space which is of most significance and the magnitude of this can vary considerably depending on whether the soil shows a pronounced or small degree of brittleness. Further examination of the interaction of the two mechanisms seems to be desirable.