IV International Symposium on Landslides, Toronto, 1984, vol. 3,pp 147-150.
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Closing Remarks

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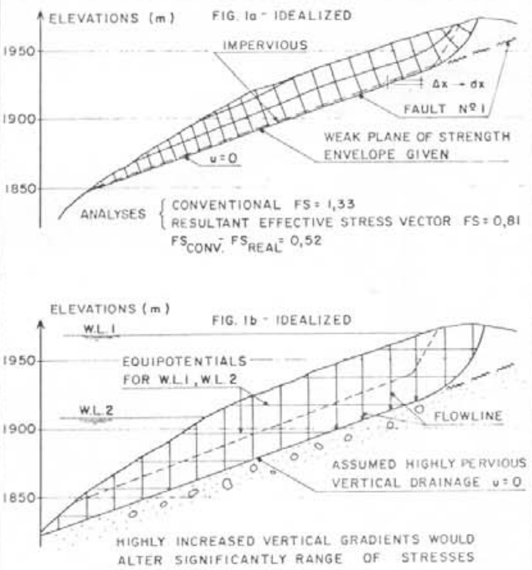
So many and so valuable have been, and are, the papers published on landslide case-histories and analyses, that the present discussion begs leave to broach the subject from a broad perspective, despite the author's humility in the face of the complexity and great responsibility of the subject, as well as in the presence of the distinguished colleagues contributing to its solutions.

The first comment is that anyone entering the subject would be led to the impression that by far the greatest proportion of papers seem to content themselves with after-the-fact reports, descriptive though complemented by adjusted back-analyses; they leave the practising professional with no orientation on how to design, calculate, predict, in reasonably a priori conditions, for the next case. Meanwhile, for the slide reported and analysed, attention centers on its management. Recommended design policies is what we really seek as engineers, ever faced with one of Nature's most inexorable types of repetitive failures, of worldwide cumulative damages already very big, and every increasing. It is commended that the State-of-the-Art lectures at this conference have begun to analyse groups of analogous case-histories in order to establish proposed design policies and increasingly realistic testing-and-computation procedures, with noticeable differentiations between different soil types and geohydrological conditions. The first point thus, is to insist on, analyses of groups of case-histories, in order to establish adjusted design-analysis procedures for each group-type.

The second comment is that we all recognize that no case of landsliding can be studied without some adequate initial reconnaissance and formulation of geological and hydrogeological features. The boon of a simplified geometry of sliding-circle that seemed necessary for ease of calculation in the 1940's and early 1950's has become the cause of many gross errors, especially in landslides, which very seldom involve homogeneous materials: it is along geological discontinuities that most big landslides occur, and it is already 30 years since Janbu's (1954) formulation permitted the "Application of composite slip surfaces for stability analysis". Whenever a natural landslide occurs, we should attempt to analyse not only why it occurred, where and when it did, but also why adjacent volumes presumed similar did not, and probably will not for decades or centuries: obviously, idealized homogeneity of geotechnical routines is but one of the domains of consequence. (e.g. Karlsrud 1984, Sallfors 1984). In a recent case of a significant slide in overconsolidated tertiary clays in which my intervention was requested, the first problem faced was that geotechnicians in good faith embarked automatically into circular slide surface analyses, whereas a geologic reconnaissance showed sliding along a dominant planar feature of weakness designated Fault No. 1 (Figs. 1 a) b)).



FIGS. Ia,b. GEOLOGIC DISCONTINUITY, FAULT Nº I INTERFERING ON STRENGTH AND FLOWNETS

The third point to recognize is that attention has, unfortunately, been concentrated on "numerous studies ... to compare the factors of safety computed by different methods" (Fredlund 1984) although Janbu (1980) had well summarized "The differences are so small that the procedures compared are numerically equal for all practical purposes", which is not surprising, when considering that the various methods are based on the same driving and resisting forces and the same equilibrium equations, while the unknown variables are interrelated. Thereupon my emphasis is on the surprise that the basic concepts have been left dormant with respect to the artificies employed (as necessary in the 1940's) for minimum adequate ease at stability calculation. The simplifying idealizations produce quite valid results in many cases, such as the one herein summarized. Therefore, since interim rapid advances in computational abilities have made it quite unnecessary to continue using the early idealizations, I propose that we should make a concerted effort to return to the basic principles for all cases. The sad reality is that very many failures that we face had incorporated well-meant and well-conducted conventional practices that we ourselves made efforts to spread and impress upon geotechnicians.

The fourth point is the principal one to be emphasized: it is the idealization that spread the facile use of slope stability analyses; it is well demonstrated in Taylor 1948 (p. 200) under the heading "Demonstration of the basic seepage force relationship". The statics (i.e. infinitely rigid) of an elemental volume between two successive flowlines and equipotentials is exactly equivalent if we consider

(a) resultant of gravity effective stresses composed with seepage effective stresses, body forces
(b) total weights and boundary neutral forces (impervious membrane hypothesis) of the elemental volume.

Thereupon "The considerations for a small element may easily be extended to a large mass by summation of forces for all the elements of volume which make up the mass" (loc. cit. p.203). The simplicity of the technique (b) literally made it practicable for professional geotechnicians to run stability analyses, and drove into total oblivion the reality that condition (a) is what intrinsically prevails in our Terzaghian soil mechanics. Moreover, from Taylor 1948 on, all studies on stability analyses with incorporation of side forces on the slices etc... have shown that the net effect, on the rigid sliding block analysed, is merely to redistribute stresses with no consequence: thus, if a linear strength equation is used, obviously the effect should be annulled upon having a Δ (stress) and consequent Δ strength) taken off from under one slice and added under another slice. The conclusions are dominantly attached to the linear strength equation.

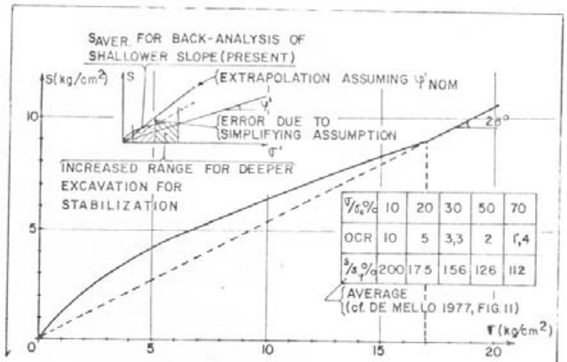


FIG. 2. CURVED STRENGTH ENVELOPE IN OCR RANGE OF CLAYS

The fifth point follows immediately, however. In reality, the importance of the curved strength envelope (especially in the over-consolidated range of highly preconsolidated clays) in geotechnical engineering has been increasingly recognized (e.g. de Mello 1977, Tavenas 1984, Silvestri 1984, etc...), and the important facts to emphasize are

(a) the very steep ds/d σ ' under low pressures significantly affected by suctions,
(b) the very significant cumulative contribution (area of resistance)

in comparison with the virgin compression φ ' extrapolated backwards. The influence of redistribution of stresses can promptly be seen to be significant even under the nominal stresses of a rigid body analysis under the idealized membrane hypothesis calculation (Fig. 2). The curved envelope and adjustment of computational procedures to accommodate it are already frequently mentioned (e.g. Charles and Sores 1984) but under acceptance of the conventional stresses under boundary neutral force hypotheses, and thus have not shown the significant influence on computed FS values (Figs. 1a), 3).

The sixth point of considerable importance also follows. It arises from the modern emphasis on back-analyses of early smaller slides (e.g. Li and Zhao, 1984). Such back-analyses are inexorably necessary and potent in themselves. The point is, however, that if a back-analysis is made on a slide of moderate dimensions (and stresses), its purpose is frequently for stabilization measures for much deeper excavations to flatten final slopes (e.g. Isaac and Dusseault 1984). The use of the parameters extracted from a lower stress range to the significantly higher stress range automatically generates appreciable error (cf. Fig. 2).

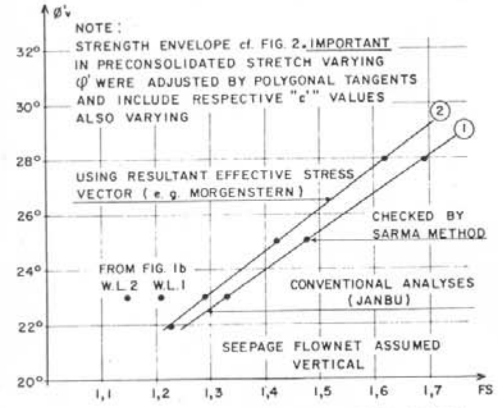
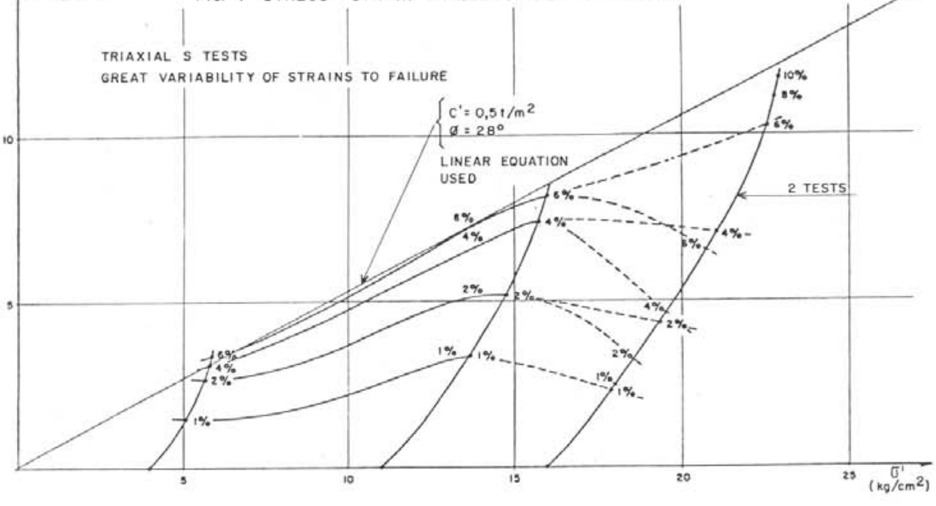


FIG. 3 COMPARATIVE FACTORS OF SAFETY FS OF NATURAL SLOPE USING CONVENTIONAL (e.g. JANBU) ANALYSES vs. RESULTANT EFFECTIVE STRESS VECTORS (GRAVITY AND SEEPAGE). CONVENTIONAL ANALYSES INCORRECT FOR CURVED STRENGTH ENVELOPES.

The seventh point regards the considerable difference that may arise between small slides (rigid body, reasonably applicable) and the very extensive slides, in which the widely different stress-strain curves in tension and at low stresses (brittle) vs. at higher stresses (plastic) (cf. Fig. 4) make the sequence of changes of stability Δ FS very important. In the case studied, sequential effects under rainfall infiltration would be reduction of suction, opening of tension cracks, cleft water pressures in cracks, and finally the establishment of infiltration flownets. Fortunately the nominal Δ FS effects exhibit much smaller variations than comparative nominal FS values, independently of initial geotechnical parameters adopted. (cf. Fig. 5).

Finally the crux of the discussion lies in my contention that for many cases, especially those of unstabilization of slopes by rainfall infiltration, the very concept of the boundary netural method of analysis is physically unacceptable. As soon as infiltrations begin, the transfer of potential energy of the water to the soil skeleton must reflect on changed stability conditions at the geologically weak boundary, irrespective of the flownet pore pressures not having reached the shear discontinuity.

FIG. 4 STRESS - STRAIN TRAJECTORIES FULL RANGE



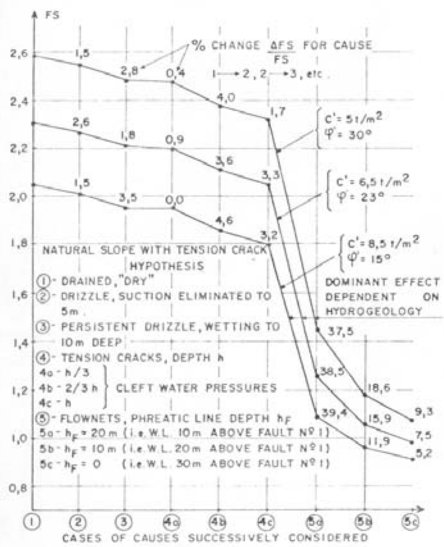


FIG 5 INCREMENTAL CHANGE OF FS ON INTRODUCING PORE PRESSURE (IDEALIZED FLOWNETS) ON FAILURE PLANE

Space limitations force us to avoid any mention of the incremental compressibility pore pressures due to rapid shear strains on such weakness planes. However, to emphasize the crucial point of the need to use only body forces for the statics, I submit comparative cases that show how often we forget that a geologic shear strength weakness plane can be associated with a significant permeability discontinuity (e.g. shown nominally "impervious" in Fig. 1a), and with strange internal drainage conditions (Fig. 1b). (N.B. in the case-history reported, the underlying rock is completely drained both by open joints and by karsts). Under the physically realistic analysis, one is immediately led to question most of the presumed cases of short-term stabilization by subhorizontal drains at the toe.

Figs. 1a and 3 show clearly the widely different results of computations of FS factors of safety, and of Δ FS, that can result. The analyses using boundary neutral forces (membrane hypothesis) are called conventional. All computations were easily programmed for hand calculator, and there was no intent to insinuate any preference for method between the principal ones widely accepted or discussed: the emphasis is on the indispensable use of body forces, except in idealized and simplified cases.

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