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## 22 - Victor F. B. DE MELLO (Brazil)

### 1. SEGREGATION IN BROADLY GRADED MATERIALS AND PIPING

Sherard's paper on « Sinkholes in dams of coarse broadly graded soils » has enticed keen discussion on a topic of great concern that is most poorly defined and investigated that of segregation in broadly graded soils. Since I have been graciously mentioned with regard to a simple technique of analysing grainsize distribution curves with regard to « how gap-graded is a gap-graded curve », I should mention that the technique had been in use by ourselves for a score of years in connection with classical grainsize filter criteria (e.g. Bertram-Terzaghi). Meanwhile there have been significant developments, and consequent revisions in my thinking and publications (e.g. my Rankine Lecture, 1977).

In considering a broadly-graded material, be it geologically dumped in foundations (e.g. piedmontic deposits, open-work gravels, etc.) or be it constructed in the embankment, one must beware of segregation of grainsizes, segregation of densities, segregation of compressibilities, and segregation of overburden effective stresses. In deterministic thinking the mechanics of piping is well enough understood : it depends on the equilibrium between erosive seepage stresses and resisting stresses from the friction component of effective overburden pressure plus any « permanent » cohesion. In inexorable statistical thinking one must recognize that piping, like cavitation, is an extreme-value problem that may in any case occur locally, and thus requires that the design and construction incorporate defensive measures, so that automatic antibody systems generate tendencies to equilibrium for avoiding progressive degeneration to general failure.

Fine vs. coarse (and angular vs. rounded, etc.) contiguous materials of incompatible densities and compressibilities are subject to the grave danger of receiving overburden stresses that vary very widely relative to the blithely assumed average $\gamma' z$ : loose pockets of fines may persist under zero overburden effective stress (with consequent zero resistance to erosions) while the surrounding less compressible dense coarse-granular structure carries much higher than average stresses. Finite Element Analyses have rendered undisputable such stress redistributions between zones of embankment dams, yet nobody carries analogous reasoning to local segregated volumes, or to layer by layer deposition of foundation materials, or to selective weathering in saprolites (cf. de Mello, 3rd Southeast Asian Conf., Hong Kong 1972).

Thus, estimated segregation of densities (and compressibilities) of fine fractions within interstices of low compressibility coarse material (boulders and gravel) constitutes a point of serious concern. Therefore, besides analysing arbitrarily separated fractions of a grainsize curve regarding grain diameter filter relationships (insufficiently correct but still dominant) one should check whether the pore volume of the coarse fraction will be filled by the fine fraction in a compatibly dense condition or not : for this, one must determine or estimate the dense dry densities of the separate fractions. Much depends not only on how broadly graded the material is, but also on the shape of the grainsize distribution curve and the compatibility of compactive behaviors of the fractions.

The true geometric comparisons should be for stereometric hindrance of core particles by filter porosimetry (cf. Rankine Lecture), but this is yet insufficiently developed. Moreover, one must emphasize that even such a reasonable geometric criterion depends on the hypothesis that grain and pore sizes remain constant, or change in a favourable direction. Pore sizes (filter) can change unfavourably if seepage stresses cause tensions or significant stress relief : that is why it is all-important to design the crossection so that on an average the seepage stresses tend to cause compressions and not tensions, favouring pore diameter reductions and the onset of arching action antibodies.

### 2. DETERIORATION, OR IMPROVEMENT. FAILURES. MONITORING

It is natural that we should concern ourselves with deteriorations with time : but we must remember that nothing stays constant with time, some cases and trends being of slow and slight improvement, others of deterioration. Embankment dams on an average improve with time (well documented : thixotropy, secondary compressions, etc. affecting probably the great silent majority of cases) and very significantly so in many compacted tropical soils benefited by micro-cementations akin to laterization : the concomitant increasing brittleness for small incremental strains may be a deterioration, however, if one is relying on « plastic behavior » in the face of any new loading.

Gradual and average trends are the appropriate domain for monitoring, for statistical development of design decisions and levels of acceptance, and for Bayesian implementation of « observational method » design adjustments. Beware, however, of the reliance on monitoring for hope of averting failure accidents (unpredictable, catastrophic). I have tried to emphasize this point in my Rankine Lecture (1977) and the cases of recent failures confirm my views. The trend is inexorable of one being seduced into the self-comforting insistence on monitoring : all the more emphatically must one warn that catastrophic failures belong to extreme-value statistics, unquantifiable for engineering purposes. The only solution against the types of conditions that lead to such failures, is by change of physical model of the project design and construction (change of statistical universe), so as to preclude the very phenomenon.

The oral discussions regarding Teton and Zeuzier Dams confirm my fears. Any monitoring implies a mental model (theorizable, repeated, average) both for locations of instruments and for interpretation of results. What are the probabilities of an instrument location and readings at crucial points and moments, and what are the probabilities that any theoretically unexpected result (presumed admonishing signal of impending failure) will be heeded as reliable and meriting prompt action? The tendency will inevitably be of further debate and investigation, to confirm on the reasonableness (i.e. average) of trends being monitored : will the job defer failure long enough for such procedures, which are inexorable as the very root of engineering science?

Monitoring has to be for improvement of theorization on nonfailure criteria of limits of impunity : only by special chance could an instrument observation help in anticipating serious accidents. That is why personal observation (visual etc.) continues to be the principal aid for averting failures or attenuating their consequences, since culturally we note the discontinuous, the different, compared with what we have assimilated mentally as reasonable (expected, repeated, average).

## 23 - J. W. HILF (USA)

During excavation of the embankment on the left abutment of Teton Dam a wet seam was exposed in the Zone I fill at about elevation 5115. Subsequent explorations in the dam remnant by adit and drill holes indicates that the wet seam, or seams, is a narrow planar, near horizontal feature characterized by low density and high moisture content. The seam apparently extends throughout the Zone I fill in the dam remnant and varies in thickness from 0.2 foot up to 5 feet thick, the thicker seams may actually represent several smaller seams. The elevation of the seam varies from about elevation 5 112 to 5 139 and apparently slopes slightly upward from the left abutment side to the right abutment side.

The 1974-1975 winter shut-down surface on the left abutment is just a few feet below the main wet seams (s). On the right side of the remnant the winter shut-down surface and the wet seam appears to be nearly coincident.

The wet seam (s) is characterized mostly by low-density-high moisture silt. Moisture samples show the wet seam is from 5 to 10 % above normal placement moisture...

Thermistor logging has been done in one hole and is planned for others. The logging in drill hole PR-100 shows that the temperature in the wet seam is about 6 degrees (C) cooler than the normal silt.

Considering that the cold wet seam was found in October 1977, 30 months after placement of this material in the fill and 17 months after the Teton Dam failure, the temperature difference appear to be significant. It implies that frozen ground or frozen borrow soil was present virtually throughout the core and nearly coincident with the winter shut-down surface of 1974-1975. When this layer melted an avenue of easy access of reservoir water through the core resulted. It is noteworthy that the remainder of the core outside of the wet seam was dry; the reservoir did not have time to penetrate the compacted core.

Since the postulated trigger mechanisms of hydraulic fracturing and differential settlement were not substantiated by the post-failure investigation, it appears to me that the most probable trigger mechanism for the failure of Teton Dam was the construction defect represented by the wet seam.

## 24 - P. D. KARNICK (Canada)

## TITAN DAM FAILURE

(1) Mr. Hilf has covered most of the points I had in mind.

(2) I would like to know if any chemical analysis of the water was carried out. And if any investigation was carried out of the chemical action of that water on the filter materials.

(3) As an example of the function of filters, I may give the example of a rock fill dam built on the unknown river in northern Canada. During the filling, large pot holes formed in the impervious till material (The till material mentioned earlier in Mr. Sherard paper). Upon dumping a mixture of boulders, gravel and till the pot holes sealed and leaks stopped.

(4) In conclusion I maintain that a well graded filter backed by an efficient and sufficient drainage system is a must. This maintains a steady hydraulic gradiant. Should this gradiant develope a discontinuity it may dry up portions of the core giving rise to cracks and thus provide the passage for the beginning of the washing of the core and eventual failure of the Dam.

## 25 - Prof. D. MILOVANOVIĆ (Yougoslavie)

On parle des ruptures de barrages. Question principale : Comment les éviter? Une des causes : les crues exceptionnelles.

Je voudrais soulever le problème des crues de référence pour lesquelles il faut prévoir des évacuateurs adéquats pour tout barrage sensible à une hausse du niveau de la retenue supérieure au niveau maximal prévu, surtout pour les barrages en terre et en enrochement. C'est ce qu'on appelle la « Maximal Probable Flood ».

Je ne suis pas du tout compétent en hydrologie, mais en tant que constructeur et projeteur principal de plusieurs barrages, je me suis trouvé confronté à ces problèmes.

Je pense que la Commission Internationale des Grands Barrages devrait soumettre cette question à l'un de ses comités techniques.

Pour des barrages qui ont des bassins versants de faible et moyenne étendue, je prends pour le moment la « Maximal Probable Flood » en prévoyant un dispositif d'évacuateur de crue destiné à éliminer toute possibilité de rupture du barrage.