DIVISION 6

Earth and Rock Dams, Slopes, and Open Excavations

Barrages en terre et en roche, talus et tranchées ouvertes

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ALTHOUGH EARTH DAMS HAVE BEEN UNDER CONSTRUCTION since ancient times the advancement in the knowledge of soil engineering and instrument techniques during the past two decades has emboldened design engineers to plan higher and higher earth- and rockfill dams. We have at the moment the 747-ft Oroville earth dam under construction in the U.S.A., and the Russians are believed to be constructing a 948-ft-high dam. Fairly high earth- and rockfill dams are also being constructed in seismic regions. It is heartening to note too that some of the recent tracer techniques and design aids have been found useful in the planning and construction of earth dams. Use of digital computers in stability analysis and the application of radio isotopes to the study of seepage problems are two examples of this trend, and there are papers on both of these subjects in the present Conference. As predicted by Trollope in his General Report to this division at the last Conference, another technique which has gained popularity over the last decade is the use of drilling mud for cut-off and trench excavations. This subject was first discussed at the Third International Conference (Zurich, 1953), as a result of a paper by Veder of Italy.

The 34 papers which were submitted to Division 6 cover a wide range of subjects but for purposes of discussion they may broadly be classified as follows: *(a)* design and construction of embankments and earthfill dams (5 papers); *(b)* design and construction of rockfill and hydraulic fill dams (5 papers); *(c)* design of cores and filters (3 papers); *(d)* stability analyses (9 papers); *(e)* embankment and slope failures (5 papers); *(f)* miscellaneous topics (7 papers).

DESIGN AND CONSTRUCTION OF EMBANKMENTS AND EARTHFILL DAMS

Gilg (6/10) deals with some problems of compaction encountered in the construction of the 150-m-high Göscheneralp earth dam and its subsequent deformations. The upstream slope is founded on silts and peat lenses which were stabilized by the provision of sand drains. The author could have added with advantage details of the installation of these sand drains. Interesting data on laboratory and field compaction, and on the properties of materials in various zones, have been given. The horizontal deformations in the dam after various stages of filling and emptying and the settlement of the top and other intermediate points have been studied over a period of four years. In this short time the dam seems to have stabilized itself and the horizontal displacements are nearly elastic.

Little (6/16) has presented an interesting account of the performance during construction of some earth dams with which he has been associated, and he rightly feels that a substantial advancement in earth-dam design is only possible if the results of field measurements are applied in subsequent designs. The author made observations of the pore pressures and measured the shear parameters and other soil properties of samples extracted from the fill, and then used these values to check the stability of the dams during and after construction. He wisely warns against the use of a negative pore-pressure concept in the design of important dams.

Bernell (6/4) describes investigations carried out to study different methods of compacting frozen soil in earth embankments, and to determine conditions suitable for its placement. This subject should be of special interest to the organizers of this Conference who have to face the problem of construction in places where temporary cold periods could occur during a favourable construction season. The author concludes that if gravel is intended to be placed while in a frozen condition the permissible moisture content should be very low. It is interesting to note that a number of dams ranging in height from 85 to 100 m are under construction in the northern part of Sweden where placement of frozen soil is permitted to a certain extent. The post-construction behaviour of these dams will be watched with great interest.

Stamatopoulos and Kotzias (6/30) describe the construction and performance of an embankment on soft clay in the sea. The part of the embankment built at sea depths between 1.2 and 2.8 m caused complete failure of the clay bed, and it is interesting to note that this was predicted from stability analysis.

Vargas, et al. (6/33) give an account of the use of residual clays (from weathering of gneiss, basalt, and sandstone) in seven earth dams constructed or under construction in Brazil. A comparison of physical properties, shear strength, and permeability of the compacted soils is given and the problems that arise in the design and construction of dams with residual soils are enumerated.

DESIGN AND CONSTRUCTION OF ROCKFILL AND HYDRAULIC FILL DAMS

Clay cores play a crucial role in the design of rockfill dams, and consequently *Anagnosti's* paper *(6/3)* describing the field performance of a 90-m-high rockfill dam in Yugoslavia is welcome. The change of stresses with time and their distribution, and the settlements in the clay core were measured. This information could be used with advantage in the design of larger dams with wide clay cores placed in steep canyons. It is encouraging to note that this analysis could enable specification of certain design procedures that would minimize the potential danger of any type of cracking in the core.

Donaldson (6/6) discusses the use of the residue of crushed ore from the gold-mining industry in South Africa as a construction material for hydraulic fill dams. The effect of drying on the consolidation and shear characteristics of the material was determined both by laboratory and by *in-situ* tests. It was found that, although heavy overconsolidation of the material occurred during drying which led to the increase in shear strength, its lasting effect was small because of the frequent rewetting and capillary effect.

Holestöl, et al. (6/13) describe the placing of tunnel spoil in a rockfill dam in Norway, and the measurement of its subsequent settlement. The measured values of settlements were compared with the computed values obtained from large oedometer tests. The paper contains interesting details of construction in the summer and winter seasons and their different effects on settlement.

Reynaud et Rosset (6/23) describe field tests to measure and control densities in the 20-million cubic yard Mont-Cenis Dam in France with a sloping clay core, a rockfill downstream slope, and a compacted earth upstream slope. The field tests are remarkable for their magnitude. The permeability tests and different methods of controlling densities and moisture content (especially radioactive techniques) are of special interest.

Sowers, et al. (6/29) have made an interesting study of the average rate of settlement in fourteen rockfill dams, and have compared this with laboratory consolidation test data on broken rocks. The authors have found that the settlement–log time curves of the actual dams approximated straight lines similar to secondary compression of soils. Laboratory consolidation tests of broken rock exhibited similar curves and the settlement rates were comparable, thus making the prediction of rockfill settlements from such tests feasible. The laboratory tests showed that the settlement rate was accelerated both by shock and by wetting of the rock. The gradation changes were ample proof that settlement results from crushing of the points of contact between rock fragments.

DESIGN OF CORES AND FILTERS

Kassiff, et al. (6/14) give an account of model experiments carried out on the design of filters for cohesive soils. The authors feel that the conventional filter design criteria based on grain size may not result in an economical design when applied to cohesive soils. They have developed theoretical formulae, verified by experimental observations, for calculating the factor of safety against piping. Experimental results showed that a fat clay may be protected by a fairly coarse filter material and that relatively high average gradients were required to cause failure even when the clay was allowed to swell under zero pressure.

Silveira (6/27) puts forward a new approach to the design of filters based on void size distribution curves. It is primarily based on Cedergren's design criteria which take into account the carrying capacity of filters. Expressions have been derived for determination of the thickness of filters and experimental verification has been offered in an example.

Wolski (6/34) describes model studies on the effect of seepage erosion in the silty clay core of earth dams making use of X-ray techniques. Pore water pressure measurement and visual examination of the sample, before and after seepage, gave a fair indication of the performance. It was observed that seepage erosion depends upon the hydraulic gradient and duration of percolation. The author has established a definite design criterion for impervious cores and filters for earth and rockfill dams.

STABILITY ANALYSES

Fyedorov (6/9) does not accept the hypothesis of the cylindrical slip surface in stability analysis of hydraulic fill dams, and puts forward the concept of two flat sliding surfaces, one being the internal surface of the side fill and the other an unknown sliding surface inclined at a critical angle to the bed plane. The analysis has been carried out under various boundary conditions: *(a)* no filtration forces; *(b)* slope being subjected to seismic forces; and *(c) seismic and* filtration forces acting simultaneously. Stability charts have been developed which make the entire design simple.

Langejan (6/15) points out that at present the value of the factor of safety chosen to be used in stability analyses is arbitrary, depending on experience, tradition, and a certain technical intuition. He suggests that a better approach would be to use the theory of probability, taking into account the extent of soil investigation and probability of failure of the earth structure. The author illustrates his thesis by an investigation of a limited number of cases.

Londe and Sterenberg (6/17) discuss the definition of the factor of safety. The conventional factor of safety which is the ratio of force mobilized to force applied is, according to the authors, inconsistent when the geometry of the slope is such that no failure occurs. From a critical study of the existing methods they conclude that knowledge of the distribution of stresses along the slip surface would be of great importance in zoned embankments and further advance in this field could be made by the use of conditions of elasto-plastic equilibrium.

Mencl, et al. (6/18) deal with three aspects of the problem. Mencl cites a case history where a slope failed due to residual stresses causing heaving near the toe. To estimate this stress, he recommends field measurements by the "removal of materials" method initiated by Sachs. He has made use of this method for measurement of the extent of a slide. The paper also describes investigations of the stability of thin layers of topsoil on the embankment slopes in four different phases *(a)* dry slope, *(b)* infiltration, *(c)* uplift and hydrodynamic pressure at the interface, and *(d)* disrupted top layer. Laboratory and field tests for the shear strength of fissured clays are described. Interesting laboratory tests on vertical and inclined samples are also described and it is observed that the latter give strengths considerably lower than the vertical samples. Field tests were also conducted for shear strength along horizontal joints and those conducted at very high pressure appear to agree with triaxial shear test results, possibly because of the closure of the fissures.

Nonveiller (6/20) points out that the moment equilibrium of a single circular slice in a slip surface, considered by Janbu, does not necessarily imply that moment equilibrium of the entire sliding element is assured, whatever shape it has. He considers the moment equilibrium of the entire slipping element and derives an implicit expression for the factor of safety which can be programmed for use with a digital computer. The expression coincides with Bishop's expression when the slip is circular.

Pietkowski and Czarnota-Bojarski (6/22) have made an interesting study of the time and rate of development of a rapid earth slide. The slide has been observed to start at the top and proceed downwards. The whole sliding element is divided into several sectors, and the time required for the centre of gravity of each to move a certain distance has been computed. Full cohesion is assumed to be mobilized when the displacement is 0.4 mm. The computed times seem to agree with the observed ones, and the senior author deserves to be congratulated that he had the presence of mind to time the slide as most of them occur very quickly and people (even scientists) are generally frightened by them.

Saito (6/24) has also given a method of predicting the time of failure of a slope after initial movement is visible. An expression has been developed connecting the rate of strain and the rupture life due to creep, and the author is of the opinion that it could be utilized universally for predicting the time of failure by measuring the surface strains of slopes.

Siniscalchi (6/28) points out that the main difficulty in the analysis of the stability of slopes is the lack of knowledge governing equilibrium except at failure conditions.

Stefanoff and Christow (6/31) describe the Maslov F_p method and have derived a graphical method for the rapid design of slopes. These methods have been applied in designing deep open pits in Bulgaria. The Maslov method assumes that Coulomb's law is valid and that the normal stress at any point is γH. The authors suggest that in actual practice it is best to start with a factor of safety of one and then apply a more exacting method to find the actual factor of safety.

EMBANKMENT AND SLOPE FAILURES

Aitchison and Wood (6/2) have provided an interesting analysis of the failure of small earth dams based on erosion of soil due to deflocculation. Dispersion of soil by the absorption of sodium ions by exchange complex and low electrolyte concentration causes outward flow of suspended clay through the pores of the soil. It is a common experience that colloidal sodium clay passes through filter paper and that clay grouts peptized by sodium salts are washed away. The authors base the susceptibility of soil to erosion on the sodium absorption ratio (S.A.R.) given by the following expression: S.A.R. $= [\text{Na}]\sqrt{0.5\,[\text{Ca} + \text{Mg}]}$, where values of [Na] and [Ca + Mg] are the concentration of soluble cations in m.e. per litre of water or soil extract. The authors recommend that satisfactory performance of an earth dam built from a susceptible soil-water combination can be achieved either by chemical additions or by raising the standard of construction control to ensure a field permeability between 10^{-5} and 10^{-7} cm/sec. The preferred compaction moisture content is at or on the wet side of the optimum.

Escario (6/7) discusses the instability arising from dumping loose materials close to the slope of poorly compacted embankments. The explanation offered is that when the adjoining fill tends to settle, it hangs on the slope giving rise to a kind of negative friction. A case history is given where such a phenomenon is believed to have taken place.

Fukuoka and Yamamura (6/8) describe the results of full-scale model tests of instrumented river embankments carried out at a number of sites. Field investigations were also performed at every opportunity at sites where failure took place due to rainfall and seepage. The *in-situ* shear strength and compaction properties are found to be different from those obtained in the laboratory and the authors advocate suitable modifications to the design of embankments in the light of these results.

Aisenstein (6/1) describes the deconsolidation of limey stones on steep slopes. Swelling of the material with the relief of stress appears to be the cause. Cracks are formed along the bedding planes parallel to the slope which in turn lead to creep or rock slides. Several instances of such slides in Israel are described.

Bolognesi, et al. (6/5) present data on piezometric observations in a tunnel below a dam in Argentina. The observations showed that pressure grouting in rock reduces seepage but does not always reduce uplift pressures. The authors bring out the inefficiency of indiscriminate grouting and suggest that a grout cut-off should only be used when a thoroughly competent and detailed analysis shows that it would be efficient and fully effective.

MISCELLANEOUS TOPICS

Goldstein, et al. (6/11) discuss the rheological properties of clays in relation to their strength and the stability of slopes. The authors feel that part of the slope fails by brittle fracture and part by plastic deformation, and that the failure starts near the bottom and proceeds upwards. The clay in the region of plastic deformations shows preferential orientation. The authors reject the idea of sudden failure with full mobilization of shear leading to a factor of safety of unity at failure. According to them there is a stability reserve offered by plastic deformation in the lower part of the slope.

Grandclement et Lauga (6/12) describe the use of nuclear tracer techniques in soil and subsoil water investigations using Iodine 131 as the radioactive isotope. They have traced the direction of seepage in the left bank of a dam in Algeria. The authors believe that the method could be used to map the variations in soil profiles.

Nash, et al. (6/19) describe the construction of a soil-cement dam and bring out the various factors which require consideration in such construction. The paper is a slight advance over a similar paper presented by Rocha, *et al.* to the Fifth International Conference (Paris, 1961). The authors point out that, besides economic considerations, certain other chemical and mechanical problems such as anisotropic permeability, sandwich layers of uncemented materials, transverse cracking, brittleness, and long-term stability need to be resolved. They therefore recommend a proper evaluation of current design methods which should also involve field trials on an experimental basis, possibly on a cofferdam, before resorting to the use of soil-cement in actual dam construction.

Piaskowski and Kowalewski (6/21) describe the excavation of a cut without strutting, lateral support being provided by the hydrostatic pressure of a clay slurry. The technique seems to have found a fair amount of application since a similar paper was presented by Veder to the Third International Conference (Zurich, 1953). In the present paper the specific gravity of the slurry has been related to the depth of the cut, groundwater conditions, and soil type. The authors have also tried activation of the clay to increase its thixotropic properties. They claim that, although activated clay may be costlier, the additional cost may be justified because of the smaller quantity of material required.

Scherrer (6/25) has presented data regarding foundation settlement of a dam in Brazil. The computed settlement values, computed by Terzaghi's formula, are normally greater than the observed values, but the two are close enough during the saturation period. The author therefore concludes that prediction of settlement can only be reliably made during the saturation period.

Shuk and Gomez Villa (6/26) present laboratory data on the effect of drawdown on the seepage characteristics of the upstream sand filter zone of the Sesquilé Dam. Model tests were carried out in steel cylinders filled with sand used at the dam site. Expressions have been derived by a statistical examination of the test data giving pressures at different points both for instantaneous and normal drawdown conditions. It was observed that water lag was completely negligible and did not affect the static factor of safety originally computed for the sand filter zone.

Ter-Stepanian (6/32) describes the open- and closed-well methods of observing creep deformations. It is claimed that these observations would make it possible to measure two rheological properties, coefficient of mobilized shear and coefficient of flow, which are related to time of plastic flow and viscosity by simple expressions. The author finally feels that these field studies are free from the limitations that beset laboratory tests. Two examples of such calculations are given based on the observation of depth creep wells on the landslide slope on the Black Sea coast of the Caucasus.

CONCLUDING REMARKS

Because of the wide variety of subjects covered in the various papers it is difficult to give any specific guide lines for discussions, and it is hoped that besides questioning certain hypotheses and statements in the papers the discussions will also bring to light new knowledge. However, the General Reporter feels that if the following topics could be highlighted in the discussions the greater benefit will accrue to all those interested in the subject.

1. Introduction of visco-elastic, visco-plastic, or elasto-plastic principles in stability analyses.
2. Mechanism of development of slips in embankments and slopes. There seems to be some controversy as to whether it starts from the top or the bottom.
3. Variation of stress with time and the effect on stability of normal stress distribution along the slip surface.
4. Creep strength of soils and its influence on the stability of slopes, with particular reference to their long-term behaviour and its effect on engineering constructions.
5. Effect of seismic forces on design considerations, especially in the case of relatively loose soils.
6. Influence of age on the strength and compressibility characteristics of soils used in dam construction.
7. New concepts in the design of filters and impervious cores.
8. Importance of the role of water tension in slope stability analyses.

REMARQUES DE LA FIN

A cause de la grande variété de sujets traités dans les divers articles, il est difficile de suggérer quelque ligne de conduite spécifique pour les discussions; il est à souhaiter qu'en plus d'examiner le validité de certaines hypothèses et énoncés, les discussions pourront apporter des lumières nouvelles sur le sujet. Cependant, le Rapporteur général croit que si les thèmes suivantes pouvaient être soulignés durant les discussions, ceux qui sont intéressés dans le sujet pourraient en tirer profit.

1. Introduction des principes visco-élastiques, visco-plastiques ou élasto-plastiques dans les analyses de stabilité.
2. Mécanisme de développement des surfaces de glissement dans les digues et les pentes. Il semble y avoir une certaine controverse à l'effet que ces surfaces commencent à se développer au haut ou au bas de la pente.
3. Variation de la contrainte en fonction du temps et l'effet sur la stabilité de la distribution de la contrainte normale le long de la surface de rupture.
4. La résistance au cisaillement des sols sujets au fluage et l'influence du fluage sur la stabilité des pentes, particulièrement en regard de leur comportement à long terme, et l'effet sur les constructions.
5. Effet des forces séismiques particulièrement dans le cas des sols relativement meubles.
6. Influence de l'âge sur les caractéristiques de la résistance au cisaillement et de la compressibilité des sols employés dans la construction de barrage.
7. Nouveaux concepts pour les projets de filtres et noyaux imperméables.
8. Importance du rôle de la tension d'eau dans les analyses de stabilité des pentes.

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