Earth Dams, Slopes and Open Excavations

Barrages en Terre, Talus et Tranchées Ouvertes

General Report

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Introduction

Since the conference at Zürich, about 500 papers have been written that deal in part with the problems which concern Division 6. Of these about 200 have been examined. The large volume of material, the unavailability of some papers, and the language difficulties have made a more complete coverage impossible. The 30 papers submitted to this Conference, and papers published elsewhere that the authors asked to have considered, are sufficient to provide us with a good cross-section of current thought on this subject, and this review is therefore limited to those papers.

Many textbooks and papers on the subject of soil mechanics start out with a statement that soil is a very complex material. A review of the current literature on the subject leaves one with the impression, rather, that the nature of soil is simple compared to the procedures men have devised for its treatment. Many different methods have been proposed for sampling, testing, evaluating and utilizing soil. Among these methods there are serious disagreements. An attempt will be made here to try to develop an explanation for this state of affairs and to locate those areas in which we should concentrate in order for progress within this field to continue. The first step in such a process is to subdivide the available information into smaller units which can more easily be evaluated.

Three separate approaches are apparent in the search for knowledge on this subject. Basically these are: observation, experimentation and rationalization. It seems desirable to classify contributions in this manner because the basis for disagreement seems to stem from the method of approach used. In the final evaluation any explanation and procedure to be wholly acceptable should successfully withstand examination by all three approaches. In a rapidly growing field of inquiry such as soil mechanics there are many contributions which have thus far been developed by only one or two of these methods of approach and are therefore still subject to further verification. Unfortunately this is not always recognized and so some of these incomplete contributions have been accepted as a foundation for additional development. As the body of knowledge grows it is necessary therefore to re-examine its foundations from time to time and to eliminate the faulty concepts.

A second method of classification divides the problems we are faced with into groups according to the factors involved. Within the scope of Division 6 such a classification includes stability and the control of water. In any practical problem both factors may be involved but customarily they have been considered separately.

A third method of approach involves division of the contributions according to type of situation into natural slopes, excavated slopes, and built-up slopes. In past practice such a subdivision has not generally been used but it seems that sufficient differences have been found to make such a division desirable at least within the field of stability.

The papers of this conference have been separated into groups for easier consideration of stability problems, water control problems, and theoretical developments. Stability problems have been further subdivided according to the type, situation and a section on material utilization is included.

Observation and Experimentation

The bulk of the available literature follows one or the other of these two approaches. One of the more notable developments is that more and more workers in this field are developing experiments to support their observations. An example of considerable interest is the studies made at the Norwegian Geotechnical Institute which involve the development of sensitivity in clay.

Those reports which may be described primarily as observations are also improving. These case histories form the background for much of soil mechanics practice and consequently are very important. One of the principal drawbacks to the more effective utilization of these experience reports is the lack of an adequate terminology for the description of soil structure. Consequently, we can correlate experiences from different parts of the world only very imperfectly at the present time.

Stability

The problem which attracts the most attention is the development of a universally applicable method for the determination of stability. The papers for this Conference show that many different procedures are in use which under some conditions give satisfactory answers and which under other conditions do not: one superior method is not apparent. The problem of evaluating these various methods is complicated by divergence of opinion both as to the proper strength values to use in analysis and as to what constitutes a satisfactory solution.

If we subdivide stability problems into those involving natural slopes, excavated slopes and fills, we note that failure of natural slopes must result from a change in soil properties in place. The determination of these changes and how they develop is then one of the basic elements in the solution of stability problems for natural slopes. Excavated slopes are founded in a natural soil structure and involve a change in load and a re-distribution of stress. The latter process may be a function of time and could account for the apparent stability of temporary excavations which fail after a period of time. Whereas excavation involves a reduction in load, fill construction involves an increase in load and should therefore require a different procedure in making a stability analysis from that required for an excavation. When these fundamental differences are recognized our chances of finding not one but a series of different procedures for the proper evaluation of stability will be materially improved.

Natural Slopes

Much of the older literature on the subject of the stability of natural slopes has concerned itself with the reporting of the process of failure and the immediate circumstances surrounding the failure. An example of this approach is given in the description of three landslides in Eastern Canada by Hurtubise, Gadd and Meyerhof (6/14). From the perusal of such papers a number of generalizations have been made. Sliding failures have been divided into two types according to the speed with which failure occurs. There are failures in which the characteristics of the soil in the vicinity of the sliding surface are greatly altered; there are others in which the soil properties are not apparently affected. Slides have also been grouped into three types according to the motivating forces; namely, removal of toe support, addition of surcharge in the upper parts of the slide area, and changes in moisture in the slide area. It is commonly assumed that some triggering action is required to set the slide mass in motion. Some attempt has been made to classify these slides according to the shape of the sliding mass.

More recently various methods of stability analysis have been applied both to failure slopes and to stable slopes involving the same soil conditions to determine the comparative reliability of these procedures. Since almost every group engaged in work of this type uses a somewhat different procedure it is difficult to correlate the findings. Nevertheless, all these procedures are based fundamentally upon Coulomb's equation for shear strength and the Swedish slip circle analysis. In contrast to previous meetings of this organization in which much support was given to the $\phi = 0$ assumption, all the investigators reporting to the present Conference find that a satisfactory factor of safety of approximately unity for incipient failure can be secured only if cohesion has a much reduced value over that secured in the commonly performed laboratory tests. This condition is not associated with soil type, region or investigator, and it is not associated with motivating forces or with the shape of the slide. Skempton and DeLory (6/24) and Henkel (6/12) have considered slides in London clay where the base of the slides approximate a plane. BJERRUM and KJAERNSLI (1956) and SEVALDSON (1956) have considered deep circular slides in clay. Vargas and Pichler (6/27) have examined residual soil and rock slides where moisture was clearly either a motivating or triggering force, and Peynircioğlu (6/20) has reported on a condition involving soil creep along with removal of toe support.

A condition common to failures in natural slopes that could have a bearing also in man-made slopes is that slopes where failures occur have often stood for years and even for centuries before failure. What then are the factors which cause this change? It is probable that not only are there a variety of factors that cause these failures since they are found in all parts of the world, but it is also probable that some specific sequence of events must first occur since it is difficult to conceive that these conditions of incipient stability could persist over such long periods of time if a single factor would produce failure. Among these factors is the production of a high sensitivity in marine clays through a leaching process that the Norwegian Geotechnical Institute has investigated. There is the deep weathering that develops gradually in tropical soils and the accompanying chemical changes in the soil constituents. There is also the mechanical rupture produced in soil strata in the colder climates through frost action and the rupture and shrinkage cracks that result from desiccation. If to these various factors that partially destroy the strength of the natural soil structure we add such changes as moisture variations due to rainfall and variations in ground water, the denudation of vegetal cover that might occur from climatic changes, fire or the action of man or animals in combination with natural or man-made activities that remove toe support or introduce surcharge, it is possible that sufficient elapse of time can occur to account for the continuing failure of slopes that for years have proved to be stable. We have scarcely begun to examine these various factors to determine the respective parts they play in the maintenance or destruction of the stability of soil structures. There may be other factors as yet undiscovered. Until such factors have been evaluated as to their influences and frequency of occurrence, we must continue to recognize the fact that generalized analyses will not provide accurate evaluations of natural slopes.

Excavated Slopes

Although the impetus for the initiation of soil mechanics has been ascribed to failures of excavated slopes, very little of the effort that has been applied to the advancement of soil mechanics has been devoted to this problem. Papers devoted exclusively to this feature are conspicuously absent in the normal reference sources where such information might be found. The usual treatment for this type of problem seems to be to excavate slopes to some angle determined primarily by customary practice and if the slope fails, to go back and flatten it or support it in some way. There probably was economic justification for such practices when they were originated (in most places where soil slopes were required). In the construction of roads, railways and canals, at the time such practices developed, the cost per unit of length was undoubtedly small and complete soil surveys along the route would have been expensive. In those locations where open cuts were temporary, equipment was usually available in case of failure to correct the situation, and so the simplest kind of soil mechanics was adequate.

In recent years the amount of work required for modern highways, railroads and large canals has become increasingly costly, and the need for the best assistance that soil mechanics can provide is becoming very apparent but its acceptance is slow.

The paper by Burke and Davis (6/9) describes the kind of investigation that might be required where a large and expensive excavation is involved. As a result of a very thorough exploration it was found that slopes in various parts would vary between 4:1 and 10:1. In the more commonly used approach the procedure might have been developed along the following line of reasoning: These materials are very similar to the London clay which Skempton and DeLory examined; they found that 10:1 slopes are required for stability; therefore, the slopes in the Grass River Lock excavation should be on a slope of 10:1. It is apparent that the thorough investigation resulted in an appreciable saving in cost.

Embankments

The observation of the performance of embankments should provide for soil mechanics the best obtainable information for the formulation of general principles of soil behaviour. However, embankments are designed to be safe, so it is only in those rare instances where judgment and experience are inadequate that we are able to learn just how close to failure are our normal design practices.

The failures of embankments reported by Peterson, Iverson and Rivard (6/19) describe a situation with which engineers will have to deal to an ever increasing extent in the future. This is the problem of the incompetent foundation. The authors have been unable to obtain a representative factor of safety using either the $\phi = 0$ or the effective stress method of stability analysis using average values of soil strength. A fair correlation is obtained using the effective stress method if minimum strength values are used. This experience indicates that in designing for such conditions either the safety factor requirements must be greater than 2 or strength factors representative of the worst conditions found should be used.

Meardi (6/16) has successfully used sand piles in solving the stability of soft foundations where, prior to this procedure, failures were occurring. His success with this procedure is undoubtedly due to encountering lenses of saturated sand or silt.

The experience in India that Rao (6/21) reports should serve to remind us that no design that can be made will prove adequate unless it is supported by careful construction procedures that are in harmony with the design requirements.

Investigations concerning performance of three dams of various ages are presented by Nonveiller (6/18) for Lokvarka Dam, Finzi and Niccolai (6/10) for San Valentino Dam, and Baroncini and Croce (6/2) for Arvo Dam. All three dams are similar in design, consisting of a thin centrally located impervious core supported by thick shells of pervious material. Based on the generally accepted principles of earth dam design all of these dams should be amply safe, and this is indeed the case. However, the observers have noted some interesting phenomena which have a bearing on the general principles of dam design. Nonveiller finds that the factor $\bar{B}$ advocated by Skempton and his associates cannot be regarded as a constant. It is doubtful whether the originators of this factor intended that it be considered as a constant except within limited ranges, and even then its use is primarily to simplify a theory. Practically all the constants and coefficients that have been introduced in soil mechanics are constants only for limited ranges, and then only with respect to the variables with which they are associated; the $\bar{B}$ factor is no exception. Baroncini and Croce find that the core material remains very soft even after 25 years for dams of this type and note that construction practices are reflected in the condition of the soil in the embankment. Finzi and Niccolai find that actual settlement agrees well with predictions if subsequent operation can be predicted. Their observations concerning pore pressure indicate a lag in pressure response for saturated materials. The apparent lag is explainable as continuing drop in pore pressure at tips during the period that reservoir levels are below the tip level.

There is sufficient information and experience available and design practices are sufficiently well established so that any well-informed engineer should be able to design satisfactory embankments provided foundation difficulties are not involved. When failures under these conditions are noted, they involve, therefore, either unusual circumstances such as over topping, insufficient care in construction, or an accepted risk in departing from normal practices.

Questionable foundations, on the other hand, continue to introduce difficulties because of variability within the zone of influence, because of the uncertainty of test results matching actual conditions, and because of the inadequacy of present available terminology for the dissemination of experience. Such problems are solved primarily on the basis of judgment. A new development in this respect is a departure from the normal definitions of safety and the proposal for evaluations based on minimum probable conditions with some qualification. It is believed that this procedure has actually been used to a considerable extent but has not, except for the $\phi = 0$ procedures, been given much publicity. It is known that engineers of the Bureau of Reclamation have in many instances and for many years required that embankments should have a safety factor of at least 1 if cohesion is neglected but pore pressure is taken into account.

Materials and Construction Procedures for Embankments

It has often been said that with a proper design almost any kind of material could be used in an earth embankment. Actually, there are many types of soil that are customarily avoided because of uncertainty concerning their long-time behaviour in spite of the rather extensive number of laboratory test procedures now available. Only as necessity forces us to utilize new materials is the range of our knowledge extended.

One of the materials that is finding more widespread use in recent years is rock-fill. Many tests have undoubtedly been made on such material but literature on the subject is scarce. In the series of papers for this conference there are two excellent reports on the tests made of such materials for the Göshenenalp Dam. Zeller and Wullimann (6/28) describe the laboratory tests and Zeller and Zeindler (6/29) describe the field tests: the research conducted was most complete. An important observation is that, whereas high densities are readily obtainable, shear strength varies considerably with small changes in density in this range. It should also be noted that these 'cohesionless materials' show in test a very substantial apparent cohesion. It is also noteworthy that if a homogeneous fill is desired lifts must be small and that, contrary to general belief, the use of sluicing water does little towards improvement of density.

The report of Schiltknecht and Bickel (6/23) concerning Castilletto Dam confirms the theoretical approach as far as some glacial materials are concerned. With sufficient care in testing, design, and construction their experiences indicate that a reasonably accurate analysis is possible when 'glacial flour', a non-plastic, clay sized soil, is used for an embankment core.

Rosa, Tartakovsky, Remiznikov and Lobasov (6/22) have described procedures by which dams of clay may be successfully built in cold weather. They report success with dumping clay clods in water heated to a few degrees above freezing when air temperatures are as low as 20° C. below zero. This procedure allows all the year round construction but its limitations and design requirements are not clear. The rate of embankment construction used with this method was relatively slow.

Bar-Shany, Korlath and Zeitlen (6/3) report on their experiences with highly plastic clays. In these materials swelling is a definite problem. They place a great deal of reliance in cohesive strength.

As a demonstration of the extremes of soil used in earth dams, Tveiten (1956) describes a number of dams in which peat was used. A peculiarity of this material is that the impervious membrane develops on the downstream face of the core; special construction is consequently required in the downstream transition zone.

The examples presented are sufficient to demonstrate the wide variety of materials that can be used for embankment construction and that theoretically at least no soil is unsuitable. It should be noted, however, that each soil with unique characteristics has associated with it either some unique design features or at least a special emphasis on some factor of design. The indication is that it would be improper to standardize dam design because it would prevent the utilization of the most economical materials and procedures.

Water Control

The design and construction of embankments very frequently involve not only problems of stability but also the problem of water control. Aisenstein, Yevnin and Saidoff (6/1) in working with reservoirs in Israel have been extremely successful by the use of blanketing in greatly reducing reservoir losses, but the particular geological situation with which they had to contend is primarily responsible for their success. The good results that were obtained with the limited data collected are not a common experience in this field.

To provide us with devices to simplify the work involved in solving problems of this kind Bernell and Nilsson (6/7) have worked out an electrical device by which two-dimensional flow can be studied both in the steady state and as a transient phenomenon. Twelker (6/26) has offered a procedure for working with the more difficult three-dimensional problem.

We do not yet know how accurately results from these procedures will compare with actual behaviour, but since the mechanisms are based on commonly used procedures their dependability should be of about the same order.

Bennett and Barron (6/5) have extended the range of their theoretical analyses for the solution of relief well problems to include the treatment of some discontinuities, and have provided a nomograph for the solution of these problems.

The control of water is not an easy problem. Many engineers have hesitated to report their experiences because of the feeling of uncertainty that they have had as to the adequacy of the procedures used. The action of water is often slow, and procedures that may initially appear to be either adequate or inadequate may with the test of time prove to be the opposite.

Soil Properties and Analytical Procedures

In an effort to attain a better understanding of the behaviour of soil structures some investigators follow the approach of examining a single element exhaustively. The procedure has merit in that it produces new ideas that serve to advance our knowledge. It also has drawbacks in that these examinations are seldom sufficiently exhaustive before conclusions are drawn, and the conclusions are often based on simplifying assumptions that may not be valid in all cases. There seems to be a popular concept that no idea is valid and useful unless it can be presented as a mathematical equation. Conversely, if an idea is presented in the form of a mathematical statement it should not be questioned, except as to the adequacy of the mathematics. In other words any assumptions which an investigator chooses to use as a basis for his study must be accepted regardless of their validity. It is difficult to examine these assumptions because they originate in other papers, frequently previous papers by the same author or by one of his associates, and at times in sources (relatively) inaccessible or in a language foreign to the reader. These features of this type of approach tend both to obscure good ideas and to perpetuate erroneous ones.

Zweck and Davidenkoff (6/30) have made some examinations of uniform grain size filters in the laboratory to determine limiting conditions under which piping occurs. They conclude that the limitations established by the Bureau of Reclamation are unnecessarily restrictive and that with increasing fineness of the soil the ratio D_{50}/d_{50} may be increased. They also conclude that the limiting value of this ratio varies inversely with the seepage gradient. Empirical relations of this type are usually established on a conservative basis to provide ample protection for the worst situation likely to be encountered. If any particular problem is sufficiently important to warrant an individual investigation, or if the designer is willing to consider a greater number of variables, Zweck and Davidenkoff's observations indicate the benefits that may be expected. Since neither the studies of the Bureau of Reclamation nor the studies of Zweck and Davidenkoff covered very wide ranges of materials or conditions, it is recommended that both conclusions be used with caution.

Bažant (6/4) has examined the conditions under which piping occurs in cohesionless soils under the combined effect of seepage pressure and vibration. He finds that the number of influential factors is so large that certain simplifying procedures must be used. He examines both the approach of using a model and also a procedure in which an additional factor representing the dynamic head are used. A pertinent reference from a Russian source prevents a full evaluation of his findings. As Bažant points out, a small amount of clay can greatly reduce the requirements for depths of cutoffs to prevent piping and, therefore, his procedures should give a conservative answer. Whether this is true only time will tell.

Myslivec (6/17) proposes that materials be compacted to a standard of density which will prevent subsequent consolidation by the superimposed load. On the basis of laboratory tests it is shown that the usual compaction standards fall short of achieving this requirement where high embankments are involved. Although such a requirement is no doubt idealistically desirable, from a practical standpoint overbuilding in dams is a simpler solution; ballasting on railroad grades would in any event be required because of foundation settlements; and on roadways settlement is comparatively unimportant. Many other drawbacks can be seen to using such procedures in practice. Goldstein (6/11) in making studies to determine why clay soils lose strength with time, found that with a given type of clay, although strength was a function of time since remoulding, the amount of strain is independent of time. If this observation is found to be generally true, he proposes a method for establishing strength–time characteristics with a single test. Ter-Stepanian (6/11) has made a theoretical study of creep phenomena and describes a hypothesis which relates shear strength with soil creep. He also has developed a formula for the determination of creep velocity. Matsuo (6/15), on the other hand, relates the change in strength of clays to cation exchange and attributes a land creep condition to this action.

Bishop (6/8) considers the effects of consolidation and drainage upon pore pressures and shows that both factors operate to reduce pore pressures. Your Reporter does not know of any way that the effect of these factors may be predicted reliably in advance of construction, and Bishop does not provide a means for making such predictions. If, however, pore pressure measurements are made on an embankment during construction and they reach dangerous values, Bishop's work shows that relief can be obtained by letting the fill set and that the relief obtained is permanent.

From time to time investigators in this field become intrigued with the question of the stress distribution in an embankment as a method for the determination of stability. The highly abstract nature of the approach and the numerous assumptions that must be made have caused engineers to avoid acceptance of these procedures. Trollope (6/25) has examined a number of problems using such an analysis and concludes that the procedure has merit.

Lazard (1955) gives a rather thorough evaluation of the more commonly used methods of stability analysis based on the principle of the curved sliding surface and proposes a somewhat related analysis which overcomes the objections which he has raised. It is probable that once the fundamental nature of the strength of soil is solved many of the various methods of analysis that have been proposed can be successfully adopted to form a satisfactory procedure for stability analysis. Until then the use of any method is very much dependent upon the skill and the judgment of the user.

An opening in the clouds of confusion surrounding the nature of soil strength was made by Hilf (1956) in his doctorate thesis at the University of Colorado. He concluded that much of the strength called cohesion in compacted cohesive soil can be attributed to tension in the water contained in the soil. He devised methods for measuring this stress and has determined that it is similar to pore pressure but opposite in sign. This observation which has been hinted at by many other observers provides a mechanism for explaining the observations of Hvorslev and Rutledge that cohesion and the strength of clays are related to water content. Using this approach as a basis many other phenomena of soil behaviour can be explained. There are probably other conditions that are noted as cohesion that can be converted to a normal stress with the possible result that when all the stressing actions are accounted for the soil strength property will reduce to a simple dimensionless coefficient of friction.

After more than 20 years the idea that pore pressure must be considered in determining the angle of internal friction is now attaining general acceptance. It is expected that the concept that much of cohesion is really the effect of another internal normal stress produced by surface tension, and applies against the effective internal friction coefficient, will experience an equally slow acceptance. A parallel might be noted in astronomy when Copernicus introduced the idea that if the solar system revolved around the sun instead of the earth the mathematics would be greatly simplified. The mathematical approaches to soil mechanics have in the past required that either cohesion or internal friction be dropped in order to simplify the work. If cohesion is changed to the product of an internal normal stress and the coefficient of internal friction, can a simple rigorous mathematical solution to problems of embankment stability be found?

Summary and Conclusions

About 20 years ago when the idea of pore pressure was introduced, two opposing methods were proposed both of which avoided really attacking the problem. One method involved the adoption of construction procedures by which pore pressure was kept small, the other adopted the idea that since the pore pressure effect was limited to influencing the internal friction component of shearing strength that sole reliance should be placed on cohesive strength. This second approach has received the bulk of the support. With further experience it is being discovered that cohesive strength is not entirely reliable. It now appears that cohesive strength is the result of a variety of phenomena which may change in the course of time. More than 20 years ago it was pointed out that cohesion varied with water content but the mechanism of this action was not explained. It has recently been shown that in over-consolidated soils in a saturated state tension may exist within the pore water to produce the effect of cohesion. More recently it has been concluded that capillary stresses can produce the effect of cohesion in unsaturated soils. There is also an indication that the interlocking of the soil grains can produce the effect of cohesion. If we now try to avoid the effect of cohesion in the design of slopes on the basis of the second method we find that we have no strength left.

In order to overcome this difficulty a variety of procedures in the method of making a stability analysis have been proposed. These methods range from various arrangements of the stress patterns in a slope, different methods of evaluating the relationships of shearing strength to shearing stress, to utilization of minimum soil strength as found by test.

Although it appears that by various ingenious methods it is possible to design safe slopes for man-made embankments with almost any kind of soil, we still virtually have no valid procedures by which slopes in natural soil structure may be evaluated. We are forced, therefore, to depend upon observation to discriminate between the safe and the unsafe condition. Although the number of such observations is constantly increasing we are handicapped by a lack of an adequate language by which soil structure, as contrasted with soil as a material, can be described. At present sensitivity is about the only useful term that has been introduced.

For discussion I would like to suggest three possible subjects:

(1) The implications involved in changing our viewpoint concerning soil strength to one in which the various forms of internal stress are evaluated to place the relationship of normal stress to shearing stress on an absolute rather than a relative basis and thereby eliminating cohesion as a factor in stability analysis.

(2) Current practices in the selection of strength values of soil on the basis of tests for use in stability analyses.

(3) Suggestions for suitable terminology to describe soil structure more accurately.

Résumé et Conclusions

Il y a 20 ans, quand on commença à parler de la pression interstitielle, on proposa deux méthodes opposées; en fait, l'une et l'autre éludaient le problème. La première consistait à prendre les mesures nécessaires pour cantonner cette pression interstitielle dans de faibles valeurs; la seconde posait comme principe que, puisque la pression interstitielle n'agit que par le terme de cisaillement afférent au frottement, on ne pouvait tabler que sur l'autre terme, à savoir la cohésion. Cette dernière façon de faire a reçu l'approbation générale. Mais, à la lumière de nouveaux résultats expérimentaux, on a découvert qu'il est difficile de mesurer correctement la cohésion. C'est la résultante d'un certain nombre de phénomènes fluctuants avec le temps. Il y a plus de 20 ans, on savait que la cohésion variait avec la teneur en eau mais on ne s'en expliquait pas le mécanisme. On a montré depuis que, dans les sols surconsolidés saturés, c'est aux contraintes de traction exercées par l'eau, qu'est due la cohésion. Plus récemment on est arrivé à cette conclusion que cette cohésion dans les sols non saturés est due aux forces capillaires. Il y a lieu de penser, par ailleurs, que l'enchevêtrement des grains peut conduire à une certaine cohésion. De telle sorte que, si l'on élimine la cohésion dans le calcul de la stabilité des pentes, il ne reste aucune force disponible, du moins si l'on adopte la deuxième méthode.

Pour venir à bout de cette difficulté, on a proposé bien des méthodes de calcul de stabilité. Les unes analysent les aspects des contraintes dans les massifs inclinés, les autres établissent des relations entre forces et contraintes de cisaillement; d'autres enfin se réfèrent au minimum de résistance du sol, donné par les expériences.

Bien qu'il apparaisse que, par des méthodes ingénieuses et variées, il soit possible de projeter en toute sécurité des talus de remblais exécutés avec toutes sortes de sols, néanmoins nous n'avons en fait aucune méthode valable pour déterminer les pentes limites de terrains naturels. Dans ces conditions, on ne peut que s'en remettre à l'observation pour distinguer la sécurité de l'insécurité. Bien que le nombre d'observations de ce genre aille en croissant, nous sommes handicapés par une absence de langage correct qui nous permette de définir un sol aussi précisément qu'un matériau. A l'heure actuelle, le mot sensibilité est le seul mot utile qui ait été introduit.

Pour la discussion, je voudrais suggérer trois sujets:

(1) Quelles sont les répercussions du point de vue selon lequel les divers aspects des contraintes tangentielle et normale n'interviennent plus suivant, leurs valeurs relatives mais suivant leurs valeurs absolues, en eliminant aussi la cohésion comme facteur de la stabilité?

(2) Choix des essais qui rendent le mieux compte de la résistance des sols en vue de l'introduction de celle-ci dans l'étude de la stabilité.

(3) Suggestions pour une terminologie appropriée permettant une description plus précise des sols.

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