DIVISION 1

Soil Properties – General

Propriétés des sols—Générale

J. E. JENNINGS, *Professor of Civil Engineering, University of Witwatersrand, Johannesburg, South Africa*

AS WITH MOST PREVIOUS GENERAL REPORTS on Division 1, difficulty has been experienced again in defining "general soil properties." The 31 papers which were allocated to the division range over a very wide field indeed, covering, as required: soils, their occurrence, classification, and description; physico-chemical properties; permeability; methods and apparatus for determining these properties; and soil sampling. But, as will be observed, other fields are also covered.

It is appropriate to ask what the Conference means when it requires papers on general soil properties, remembering always that consolidation and shear strength are topics of other divisions. It might perhaps be useful to try to find another title for this division and to write down a few subheadings which would permit a simpler classification of the subjects which the division attempts to cover, as follows:

BASIC FACTORS IN SOIL ENGINEERING

Engineering geology
Soil exploration and sampling
Soil particles, their size, shape, and surface activity
The interrelation of the soil phases—solids : water : gas
Special soil problems

Many papers allocated to the division deal with soil problems which are highly specialized or regional, and both authors and conference organizers find difficulty in fitting such contributions into the present divisions. Hence, in the above classification it is felt useful to have a comprehensive subheading, "special soil problems," to encompass such papers. If, with the passage of time, any particular special problem starts to predominate, then the time will have come for a further separate division in the Conference.

National Committees have been very helpful in providing information on developments during the interconference period but again great difficulty has been experienced both by the National Committees and by the General Reporter in deciding just which contributions should be included in the report on this division. Where omissions have been made it is hoped that delegates will draw attention to such work conducted during the interconference period. The arrangement of the subjects of this general report has been slightly changed from that in previous general reports.

ENGINEERING GEOLOGY

This most important section of soil engineering has not received much attention and only four papers make reference to it. *Jennings, et al. (1/11)* discuss an interesting and unusual problem resulting from the solution of limestone by normal geological progress. In a local region of South Africa where water-table lowering is taking place, a karst topography is in the process of developing. Severe enclosed subsidences and sinkholes have occurred, sometimes with loss of life. The mechanics are related to arching in discharging bins, a sinkhole being caused by collapse of the roof of an air-filled void located in the unconsolidated residuum overlying a highly irregular dolomite surface.

Kantey and Morse (1/12) claim that soil engineering maps produced from stereoscopic examination of aerial photographs have delineated areas of soil having similar properties. These maps have considerably eased the problems of road location and exploration for road-building materials; considerable economies are also claimed in sampling and testing.

Nascimento, et al. (1/18) deal with the important question of when a geological material is a rock or a soil. This question is of considerable significance to engineers who have to deal with soils which are residual from the *in-situ* decomposition of rock or, alternatively, with soils which have been cemented by nature, such as ferricretes (laterites) and calcretes. It is also of importance in newer processes where organic materials are being used for a stabilization which involves some degree of particle cementation. Up to the present a soil is a material which will disintegrate when agitated with water whereas a rock will not disintegrate; alternatively, a rock can be cored with an ordinary single tube core-barrel using water as a drilling fluid whereas a soil requires more refined drilling procedures. *Nascimento, et al. (1/18)* describe a new index for petrifaction, namely the ratio of the saturated water content of the material at its natural volume to the water content of a natural sample which has been oven dried and then allowed to absorb a maximum of freely available water. This ratio gives a degree of petrifaction and is of particular interest to all engineers concerned with stabilization problems.

Rosenqvist (1/25) has given the results of a number of tests on building stones used in Norway. The data on properties such as Young's modulus, tensile and compressive strengths, density, porosity, and swelling will be of use to other workers. An interesting observation is the large swell observed with some of these natural stones.

The engineer dealing with the soil is interested in many aspects of engineering geology which have not received attention in papers to the Conference. As examples, the following topics might receive attention: the mineral changes which occur during weathering of rocks or in environments of good and poor drainage; the behaviour of jointed rock masses and pore-pressure effects in jointed rocks.

SOIL EXPLORATION, SOIL SAMPLING, AND *in-situ* TESTS

Andresen, et al. (1/2) report a new type of thin-walled fixed-piston sampler, operated by the release of a gas charge which drives the sampling tube forward into the soil. The sample tube is about 50 per cent longer than that recommended by Hvorslev, but nevertheless good samples are claimed. While the instrument is devised for use on the sea floor it might also have application in boreholes which are filled with water.

Begemann (1/4) deals with a new application of the Dutch deep-sounding apparatus, modified to include a local friction-measuring sleeve. It is noted that the ratio of cone resistance to local friction depends upon the nature of the material penetrated and clear differences are recorded for sands and clays. Tests have shown that the ratio may be used to differentiate between quite small differences in grading. This allows a soil profile to be drawn from the results of a single deep-sounding test, thus obviating the need for a separate adjacent borehole simply for this purpose. This is an important development in a device which has been widely applied throughout the world.

Lundström and Stenberg (1/15) deal with the important problem of deciding whether a drill is penetrating solid country rock or whether it is merely intersecting large boulders or detached masses of the rock. They have used an underwater microphone in an adjacent borehole, up to 100 m distant, and have observed the noise made by the drill. Analysis of the noise spectrum allows deduction of the type of material being drilled. It is possible to distinguish soil, boulders, loose rock, fractured rock, and solid rock.

Meigh and Greenland (1/16) describe *in-situ* plate-loading and Ménard pressuremeter tests in boreholes in mudstones, sandstones, and marl in England. The results are compared with laboratory triaxial tests on undisturbed cores. Good agreement between all methods is obtained when the strength does not exceed 2 tons/sq.ft. but with stronger materials the triaxial tests underestimate the strength. The methods of drilling and sampling have important effects on measured strengths.

PHYSICO-CHEMICAL RESEARCH ON SOILS

Arnold (1/3) examines the results of consolidation tests on two bentonites: one a commercial bentonite and the other a sodium bentonite prepared by NaCl treatment of the same commercial bentonite. As the void ratio decreased he observed certain changes in behaviour of the permeability coefficient. Examined in terms of interparticle attractive forces and osmosis principles he deduces that as compression, under external load, takes place the interparticle distances are decreased until a point is reached where the surface attractive forces start to predominate over the external loadings. At this point an apparent collapse takes place. This is important work in the basic understanding of the compression of clays.

Biarez, et al. (1/5) discuss in general terms the rheological laws governing the behaviour of a group of grains constituting a soil skeleton. The role of the pore fluid on changes of configuration of the soil skeleton was considered and it was concluded that a degree of saturation of 40 per cent was the most useful in a study of the properties of a particular sandy clay under repeated loading. The relation between isotropic and anisotropic consolidation is discussed and useful values are quoted showing the difference between moduli of deformation in both cases. The authors also show that the coefficients for Young's modulus and Poisson's ratio for drained and undrained triaxial tests can be related mathematically. These findings are tested in the laboratory.

In many cases the colour of a soil provides important information on its origin and environment. *Coleman (1/6)* gives a method of measuring colour which is more precise than that ordinarily furnished by colour charts; he measures the reflection spectra and relates these to the chemical compounds which are present in the soil. Iron in its various oxide forms is the main source of colour in soils. This is an important paper for engineering geologists interested in the development and measurement of soil profiles.

Eichler and Kazda (1/8) describe measurements of temperature gradients in an oedometer sample provided with a single-line source of heat. This shows a radial heat flow and is claimed to be of use in problems relating to hot foundations. They also describe X-ray and electron microscope studies on kaolinite, showing that under certain conditions, such as drying, particle stacking takes place, but in dispersed water mixtures the particles are oriented in a random fashion.

Kolbuszewski, et al. (1/13) find that ordinary Atterberg limit tests may not provide a complete picture of clay minerals and their activity, particularly in soils where there is a possibility of particle aggregation or particle cementation by compounds such as hydrated iron oxides. In such cases the use of further parameters such as moisture adsorption and base exchange capacity are necessary for a satisfactory explanation of behaviour, particularly swelling and loss of shear strength with gain of moisture.

The exchange of base and a possible stabilization effect by aggregation or cementation is of interest to the engineer who is anxious to render soils hydrophobic. The replacement of bases with organic cations, usually of a proprietary character, is an increasingly interesting trend in stabilization.

Müller-Vonmoos (1/17) shows that the ordinary sodium hydroxide test is not reliable for estimating the amount of organic matter present in a soil or for predicting the change in value of the liquid limit caused by the presence of organic matter. A new test which is at present unknown is required for the latter purpose, but it is pointed out that displacements in the value of w_L may also depend on factors other than the organic matter content. For plain organic matter determinations the titration methods of Walkley and Black provide the best current procedures.

Reséndiz (1/22) presents what may be one of the most important papers of this division—an attempt to co-ordinate theory and observation of the physico-chemical behaviour of clay-water mixtures. In its present form the paper may not be adequately comprehended by most engineers since it is based upon an understanding of physics which is generally beyond their training and experience. It will be necessary to rely on the judgment of delegates with special interests in physics. It is hoped that they will discuss and agree on these ideas and principles before others embark on the extended basic study which is required for this understanding. *Reséndiz (1/22)* puts forward a two-phase model for a clay-water system. The first phase is composed of a fluid containing free ions of water together with exchangeable cations of dissolved salts, all of which together give to the phase mechanical and electrical properties which vary with the nature and concentration of the ions and with the distance from the surface of the clay particles. The second phase is the solid phase of the clay particles which carry surface negative charges. The interactions of these two phases are examined in terms of physical laws relating to dielectric properties and polarization by the electrical field. This examination leads to conclusions regarding the states of the water in the vicinity of the particles, conclusions which are extensively supported by reference to the work of others.

With the aid of an electron microscope, *Sloane (1/28)* describes studies of the kaolinite–hydrated-lime reactions. He extends the work of Eades and Grim, showing that the action of the hydrated lime on the kaolinite involves a dissolution of the kaolinite around the edges of the particles. Calcium-aluminium silicate is formed and this increases with time. Authigenic kaolinite is also formed but this subsequently disappears. Although these studies are made with pure materials which may be very different from field materials, the paper should be of considerable interest to engineers who are interested in the stabilization of soils.

While the papers in this section on physico-chemical effects are of undoubted interest, one is left with a feeling that this report by no means covers the progress which has been made since the Paris meeting in 1961. The names of certain notable workers are markedly absent. Jorgensen and Rosenqvist in Norway have carried out investigations on the bonding of ions in micaceous materials; Martin of the United States has carried out similar significant work on clay minerals with reference to engineering behaviour; and other papers sent by the National Committees have shown that most countries are engaged on some work related to physico-chemical effects in soils. But much of this work is reported as portions of wider projects, and the sorting out which is necessary is appreciable. If the international conferences are to serve their full purpose, some continuing organization for the collection and collation of such information is necessary.

FROST HEAVE

Freden (1/9) treats the growth of ice lenses in soil in terms of temperature gradients and shows that soil particles tend to be displaced in the direction of the gradient. His theoretical deductions relate to the thickness of the boundary layer and his work is supported with the results of tests. It will be of interest to compare his observations with those of *Reséndiz (1/22)*.

Járay (1/10) finds that there is a linear relation between total heat extraction and frost heave. The constants defining this straight-line relation vary systematically with changes in the chemical nature of the pore water. The mathematical relation can be expressed in terms of maximum grain size and surface area of the soil. Similar relations involving the liquid limit are also claimed.

The frost heave problem appears to have a physico-chemical background and it is to be hoped that during the Conference these relations may emerge.

FACTORS AFFECTING THE SHEAR STRENGTH OF SOILS

Although Division 2 deals specifically with the shear strength and consolidation of soils, these properties are mentioned as well in some of the papers in Division 1.

Crawford and Eden (1/7), dealing with the highly sensitive Leda clay of eastern Canada, describe a very comprehensive study of the strength properties of this clay, drawing extensively on the results of *in-situ* vane tests and laboratory triaxial tests on samples recovered with thin-walled samplers. Considerable reference is also made to experience with similar clays in other parts of the world. The work points to the great importance of sample disturbance and also to a general questioning of the accepted interpretations of triaxial test results. This is a very important paper for all who have to deal with sensitive clays.

Rousseau, et al. (1/26) discuss the relation between the liquid limit, the plastic limit, the plasticity index, the natural *in-situ* water content, and the value of Young's modulus as measured with the Ménard pressuremeter. This work has been done on three horizons of a soil profile in clay at the base of the French Cenomanian series (Upper Cretaceous system). Very good agreement among the results was obtained.

Youssef, et al. (1/29) re-examine the relation between the Atterberg limits and the strength and compression characteristics of clayey soils in the United Arab Republic. They again find that the liquid limit does not represent a single low strength but that it varies with the soil tested. However, from strength tests conducted with a laboratory vane, they deduce a linear relation (on log–log scale) between water content and strength. Similarly, a relation is found between water content and strength at the liquid limit. These facts allow a new one-point method of determining w_L from the laboratory vane test. The authors also find relation between liquid limit and plastic limit, and hence between liquid limit and the compression index (C_c). Skempton's relations between C_u/P and I_P are reaffirmed.

SPECIAL PROBLEMS OF SETTLEMENT IN SANDS

Larionov (1/14) makes an interesting and important contribution to the understanding of the additional settlement due to collapse of grain structure when loaded loess soils and soils of similar types, e.g. low-density decomposed granites, become wetted. The features of slow and fast collapse are analysed and shown to be due largely to the structure of the grains, soils with aggregations behaving differently from those with discrete grains. Very useful indices, the humidity factor and water resistance coefficients, are introduced in the study of potential collapse.

Sands present unusual settlement problems and *Réthátí (1/23)* deals with an extension of the problem of additional settlement of loaded foundations due to collapse of grain structure after wetting of the subsoil. This problem has previously been associated with soils of a loess type but *Réthátí (1/23)* reports that the same phenomenon may occur with normal clean sand, even when the loads are negligible, as in the case of a pavement on a sand subsoil which becomes wet. A method of estimating the probable subsidence is based on void ratio changes with changes in degree of saturation. This is an important problem in partly saturated subsoils and is of interest to all who are concerned with constructions above the water table.

Zolkov and Wiseman (1/31) describe work in Israel on dune and beach sands, pointing out that the *N* values obtained from standard penetration tests should be corrected for overburden pressure. The corrections recommended by the U.S.B.R. agree well with field tests conducted on a site where a large excavation was made and the overburden pressure was reduced. The observed settlement on this site showed that the settlement under constant applied loading was a linear function of foundation width, following the elastic type of relation rather than the Kögler-Terzaghi function, $[2B/(B + n)]^2$. This result is considered to be due to the residual horizontal stresses remaining in the subsoil after the excavation is made.

SPECIAL PROPERTIES OF PARTLY SATURATED SOILS

Partly saturated soils are responsible for a substantial portion of the work of the engineer concerned with problems of the soil. The complexity of road foundations arises from this cause and such problems as heave and additional settlement due to collapse of grain structure arise from changes of moisture content after completion of the structure. Contrary to experience with fully saturated soils, the problems of partly saturated soils are associated with increasing pore pressures or otherwise decreasing effective stresses with the passage of time after completion of the structure.

A method of estimating the potential expansiveness of compacted clay soils is given by *Ranganatham and Satyanarayana (1/21)*. This is based principally on the shrinkage index, defined as $(w_L - w_S)$ of the disturbed soil. The method is developed mathematically, starting from a relation for swelling potential proposed by Seed, *et al.* The method represents an advance on other previously proposed measures for estimating potential expansiveness.

Dos Santos and de Castro (1/27) deal with the assessment of the erodibility of soils, a problem which is of the greatest importance to engineers concerned with all branches of soil conservation. They review the many previous attempts which have been made to lay down criteria for defining soils which are liable to erosion problems and, starting with soils of known field behaviour, come to the conclusion, which they view as tentative, that the percentage swell and grain size factors are the most important data in judging the erodibility of a soil. The paper represents a considerable advance on previous work in this field.

STATISTICAL CONTROL IN SOIL ENGINEERING

Kantey and Morse (1/12) pay attention to the interpretation of the results of a limited number of tests and claim considerable benefits from the use of statistical methods. The methods involve the use of the Student's t tables and this allows the engineer to use limited data with much greater confidence.

Zlatarev (1/30) uses a statistical approach for the determination of the minimum number of soil samples. This method is very similar to that of *Kantey and Morse (1/12)* and, taken together, these two papers submitted quite independently give confidence to the proposals. *Zlatarev (1/30)* points out that there are a number of factors affecting the problem: *geological*—uniformity of deposits; *technical*—features of the structure and performance requirements; *economic*—problems of justifiable expenditure; and *organizational*—capacity of plant and personnel for undertaking the work. All of these factors must be considered concurrently.

SPECIAL REGIONAL AND OTHER PROBLEMS

This subsection deals with those papers describing special regional soil problems or other problems which do not easily fall under one of the previous subheadings.

Adams (1/1) describes the results of laboratory and field tests involving the construction of trial embankments on Canadian muskeg. These results show that peat (muskeg) is essentially a frictional material with a high friction angle (48°) with respect to effective stresses. It is very compressible, with compressions up to 30 per cent under increments of stress as low as 1 ton/sq.ft. During this compression the coefficient of permeability changes appreciably, as the logarithm of the sample thickness. The compression takes place in two stages: a primary compression in which the water is expelled from the pores between the "grains" of peat and a secondary compression in which the water is extruded from the "grains" themselves. In terms of consolidation theory the secondary compression is appreciable and during this stage smaller, but clearly measurable, pore-water pressures are recorded.

Novais-Ferreira and Correia (1/19) deal with the special problems of laterites, lateritic concretions, and ferricretes which are found mainly in regions with lower water tables. These materials are very popular for road building but it has been appreciated that there are good (harder) and poor (softer) laterites for this purpose. An attempt is made to give rules for discriminating between these limits. It is found that the harder laterites are higher in iron and have a higher particle specific gravity. Hardness is tested by standard treatment in the Los Angeles abrasion machine and an index based on a ratio of grain sizes is used to differentiate between poor and good material.

Pellegrino (1/20) examines the properties of Italian coarse-grained soils of fluvial, glacial, talus, and conglomerate origins and concludes that grain size distributions are characteristic within each group. A relation is found between dry density and grain size distribution: shear strength is a function of dry density but compressibility depends mainly on origin.

An interesting development for the solution of flow nets in hydraulically anisotropic soils is described by *Röhnisch and Marotz (1/24)*. A sophisticated electrical model has been built and the resistances in the horizontal direction may be made different from those in a vertical direction. Flow of electricity is analogous to the flow of water. Several more interesting and difficult boundary conditions have been fed into the model with satisfactory results. The work will be of great interest to all because the problems of flow in anisotropic materials are so common. The results of such studies have important design effects, particularly on exit conditions at the downstream toes of dams.

RECOMMENDED SUBJECTS FOR DISCUSSION

It is recommended that the following subjects be considered for special discussion.

1. The physico-chemical behaviour of clay-water mixes. A good start for this discussion might be the paper by *Reséndiz (1/22)* and it is to be hoped that contributions can be made by others who have dealt with similar subjects including the problems of frost heave, sensitive clays, peats (muskeg), etc.
2. The problems of partly saturated soils, in particular questions of heave, swelling, loss of shear strength with time, and additional settlement associated with collapse of grain structure.

3. The statistical interpretation of soil data.

It is hoped that in these discussions authorities who have not presented papers on these topics will come forward to give the Conference the benefit of their experiences in the inter-conference period.

SUMMARY AND CONCLUSIONS

Although the 31 papers to be presented to this division are interesting and make important contributions, one cannot help but be disappointed that some persons who are acknowledged authorities in several of the fields covered have not come forward with papers. If the Conference is to succeed in its object of reviewing progress each four years, then it is important that the progress be properly reported to each Conference. The question must be asked how this could be better achieved and the following suggestions are made.

1. The scope of Division 1, "Soil Properties—General" is poorly defined and should be restated. It might be completely recast as suggested at the beginning of this report.
2. An author who has a substantial contribution to make is often not attracted towards writing a paper of the limited length required by the Conference. In each division, a selected number of authors of acknowledged reputation might be invited to prepare papers and they might be given two or three times the length of papers which are not specially invited in this way.
3. National Committees should be encouraged not to submit papers which deal with two or more diverse subjects.
4. For the next Conference the general reporters might be appointed within 12 months after the end of this Conference. It should be the duty of a general reporter to review papers within his division over the whole of the inter-conference period. National Committees should keep the general reporters informed of developments within the divisions of the Conference.
5. The general reporter of each division should be asked to recommend to the Executive Committee the names of persons who might be specially invited to submit papers within his division, as in item (2) above.
6. All of the divisions of the Conference should be re-examined and their scopes should be critically reviewed with a view to making them more definite.
7. To reduce the burden on the general reporters the number of divisions might be increased.

SUJETS RECOMMANDÉS POUR LA DISCUSSION

Il est recommandé que les sujets suivants soient considérés pour fin de discussion:

1. Le comportement physico-chimique des mélanges eau-argile. L'article de *Reséndiz (1/22)* pourrait servir de point de départ à cette discussion et il est à souhaiter que des contributions puissent être apportées par ceux qui ont traité des problèmes identiques, incluant les problèmes de soulèvement dû au gel, des argiles sensibles, des terrains organiques (muskeg) etc.
2. Les problèmes des sols partiellement saturés, et en particulier les questions de soulèvement, de gonflement, de perte de résistance au cisaillement en fonction du temps et du tassement additionnel relié à l'effondrement de la structure des grains.
3. L'interprétation statistique des données sur les sols.

Il est à souhaiter que durant ces discussions les auteurs réputés qui n'ont pas présenté d'articles sur ces sujets viennent faire profiter l'assemblée de leur expérience accumulée durant la période qui s'est écoulée depuis le dernier congrès.

SOMMAIRE ET CONCLUSIONS

Quoique les 31 articles présentés dans cette division soient intéressants et comportent des contributions importantes, l'on ne peut s'empêcher de déplorer que certains auteurs reconnus dans les divers domaines traités n'aient pas présenté d'articles. Pour que ces congrès puissent remplir leur objectif qui est de faire une revue des progrès tous les quatre ans, il est important que ces progrès soient adéquatement exposés à chaque congrès. Pour mieux atteindre ce but, les propositions suivantes sont présentées:

1. Le contenu de la Division 1, "Propriétés des sols—Général," est mal défini et devrait être délimité à nouveau. Tel que mentionné au début de ce rapport cette division pourrait être complètement refondue.
2. Un auteur qui aurait une contribution substantielle à présenter ne ressent souvent pas d'attrait à l'idée d'écrire un article d'une longueur aussi limitée que celle requise par le Congrès. Dans chaque division, quelques auteurs de réputation bien établie devraient être invités à préparer des articles dont la longueur pourrait être deux à trois fois celle allouée pour les articles courants.
3. Les Comités nationaux devraient être incités à ne pas accepter d'articles traitant de plus d'un sujet.
4. Pour le prochain congrès, les rapporteurs généraux devraient être désignés moins de douze mois après la fin du présent congrès. Le rapporteur général devrait avoir comme responsabilité de faire la revue des articles présentés dans sa division durant toute la période entre les deux congrès. Les Comités nationaux pourraient alors tenir les rapporteurs généraux au courant des développements à l'intérieur de chaque division du Congrès.
5. On devrait demander au rapporteur général de chaque division de recommander au Comité exécutif les noms de personnes qui devraient faire l'objet d'une invitation spéciale à soumettre un article dans sa division tel que mentionné ci-haut à l'article 2.
6. Toutes les divisions du Congrès devraient être examinées à nouveau et le contenu de chaque division devrait faire l'objet d'une révision critique et être mieux délimité.
7. On devrait également accroître le nombre de divisions dans le but de réduire la charge des rapporteurs généraux.