Techniques of Field Measurement and Sampling

Méthodes de mesure des caractéristiques des sols en place et prélèvement d'échantillons

General Report

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Introduction

The twenty two papers, which have been submitted to this Division, constitute a large increase since the Fourth Conference in London where nine papers were presented. It may illustrate how Soil Mechanics and Foundation Engineering circles are becoming aware of the growing importance of measurements in the field and of sampling technique. Both subjects of this division serve essentially the same purpose.

At the root lies the growing development of soil mechanics as an engineering science. Improved methods of calculation make a more economic design of foundation structures and the use of a lower factor of safety possible. For that purpose it is necessary to ascertain the various properties of soil as accurately and precisely as possible. Such properties can be determined in the laboratory and in the field.

For testing soil in the laboratory samples have to be taken, which should be as undisturbed as possible. Every disturbance can cause deviations in the laboratory results and thus lead to false conclusions as to the actual behaviour of the soil in the field.

Excellent sampling procedures have been invented, some of which are to be found in the contributions to this Division; still none is flawless.

Therefore there is a growing tendency to measure soil properties directly in the field.

One of the best known methods is the cone penetration test, many papers of this conference being devoted to that method. As a simple and reliable apparatus the penetrometer attracted special attention during the Fourth International Conference in London 1957, when a committee was appointed " to indicate the proper procedure for the recommended static and dynamic penetration tests so that the results of such tests are uniform". Several contributions in this Division deal with the cone penetration test.

Other contributions in which the determination of soil properties in the field is treated, concern :

- the measurement of permeability by pumping;
- investigations concerning oscillatory behaviour of soil;
- the measurement of density with aid of radio-activity;
- investigation of looseness of sand by blasting;
- in situ shear tests.

Finally there are a number of papers which deal with field measurements in which for instance soil movements and scouring are recorded and a full scale test is executed.

The general report is set up in accordance with the above given main topics.

Soil exploration and sampling

Begemann (2/2) describes a device for taking soil samples of 10 to 20 m with about 3 cm diameter. Heavy fluid or mud is applied in the method which tends to decrease the friction between sample and sampling tube. The sample is cut into pieces of about 1 metre length which can be ranged one besides the other to visualize the boring profile. This kind of undisturbed sampling is used for reconnaissance purposes. The device can be pushed into the ground by ordinary cone penetrometer apparatus within a short time.

For taking undisturbed samples for laboratory investigations (length 1 m, diameter 6·6 cm) a device is used in which the friction between sample and sampling tube is decreased using a plastic foil. The sampler is forced into the ground by a 15-ton press.

Dupeuble (2/4) gives particulars about the adaptation of an apparatus for making piles by boring to obtain large sized samples, diameter about 50 cm. The sampler is driven into the ground by vibration. The aim of the apparatus is mainly to supply reliable reconnaissance borings especially in soil which contains gravel and boulders. Also a sampler is mentioned which is driven into the ground by hammering.

Undisturbed sampling in loose sand has been done by Friis (2/6), who reports about successfully taking samples from great depth in Norway with more than 50 per cent voids volume. 54 mm and 40 mm diameter samplers have been used, the bore hole being kept intact with drilling-mud. The sampler is forced down by means of pully blocks. The author reports that good results for normal building purposes are obtained.

Another sampler, with about 7·5 cm diameter, has been designed by Hong (2/8), for the operation of which a casing is necessary. The advantage however, as the author says, is the omission of piston rod extension to the surface which simplifies the sampling technique compared with other methods.

Shockley, Cunny and Strohm Jr. (2/16) mention the results of investigations of the change in density in sand caused by undisturbed sampling. In general loose material increased in density and dense sand decreased in density during sampling.

Cambefort and Mazier (2/3) give details of a sampler for taking undisturbed samples in which the cutting edge adjusts itself automatically by way of a spring to the hardness of the soils encountered. In very hard soils the cutting edge for normal soils is withdrawn behind a heavy type of cutting edge.

The above mentioned papers give interesting details for the soil mechanics engineer, of which he can take his advantage in the normal practice of soil investigations. It is regrettable that there are not more papers which contribute to more fundamental research on undisturbed sampling. It should be emphasized that such research is extremely important, as progress in this field will enable soil mechanics to take a step forward.

Cone penetropeter test

A number of contributions give proof of advance in this field. GAMSKI (2/7) refers to the difficulties encountered in determining the bearing capacity and shearing resistance of soil when tests are performed on undisturbed samples; therefore attempts are being made to improve the cone penetration test and its evaluation. The author describes an apparatus which is easy to handle due to its low weight The counterweight necessary for pushing the cone down into the earth is increased by a drill, which is bored into the ground just above the cone. It should be remarked that, if the upward force exerted by the drill is considerable, it may have its influence on the cone resistance as it tends to decrease the overburden pressure.

KALLSTENIUS (2/9) gives interesting details of the Swedish rotating penetrometer which was shown at the European Conference on Stability of Slopes in Stockholm [1955]. Although the rods with which the cone is forced down into the earth are not protected against soil friction by means of enveloping tubes, the cone pressure can be derived from the measured vertical load and horizontal moment, which are exerted on top of the rods.

The author tried cones with various point diameters and varying length of the mantle. The measured resistance, expressed in terms of kg/cm^2, decreases as the diameter of the point increases. The influence of the mantle length is considerable according to the tests : the resistance measured with a mantle, which is two times the point diameter, is twice as high as the resistance measured without a mantle. The author recommends the use of mantle length equal to the diameter.

Kallstenius' tests clearly show once more the importance of standardization of the cone penetration test.

Another advanced type of cone penetrometer was reported upon by Hvorslev on the Third International Conference in Zürich [1953]. SHOCKLEY, CUNNY and STROHM Jr. (2/16) describe the use of this rotary cone penetrometer for the investigation of the stability of Mississippi River banks in which flow slides are observed (trees on the bank fall with the tops pointed riverward, etc.).

For the interpretation of the readings tests have been performed in a laboratory tank with three different kinds of sand at different relative densities and overburden pressure. The penetration resistance recorded cleary showed dependency on density, overburden pressure and the shape of the grains of the sand material. The authors also report that the horizontal pressure in the tank, which was recorded by pressure cells, is a factor of influence. From these carefully performed tests it may be concluded that the cone penetrometer, as was brought forward by Plantema, on the Fourth International Conference in London [1957], can be used to investigate the density of sand, but not without calibration to account for horizontal stresses and composition of the grain material.

MEIGH and NIXON (2/13) stress the circumstance that elaborate methods are necessary to obtain undisturbed samples of sand and gravel below the water table and advocate therefore in situ tests. In their paper plate loading tests, standard penetration tests and Dutch deep sounding are mentioned.

They conclude that in fine sands the standard penetration test gives a reasonable, if somewhat conservative estimate of the bearing capacity; in sandy gravels and probably in well graded sands and gravelly sands too the bearing capacity is being under estimated by the standard penetration test.

The Dutch penetrometer gives reliable results in all the cases mentioned. In evaluating the results of the measured cone resistance a method of De Beer and Martens [1957] was used.

The paper includes a series of case records, in which the tests mentioned were used.

RODIN (2/15) performed similar investigations; he reminds of the fact that sometimes undue reliance is placed on the results of the standard penetration test, which Terzaghi and Peck clearly have indicated as to serve as an approximate guide only.

From the tests the author concludes that the results of the standard penetration test performed in borings 15 cm or greater in diameter and sunk by means of a shell do not give a reliable indication of the relative density or bearing capacity of sand and gravel. In the case of a dense sand or gravel, as resulted from plate loading and static penetration tests, the standard penetration test seems to indicate a too low density.

A dynamic penetrometer gives more reliable indications and is recommended by Rodin as an inexpensive and rapid method of exploration.

Finally attention is drawn on the influence of the water table on the dynamic penetrometer resistance, which is done also by SCHULTZE and MENZENBACH (2/17), who performed tests with the standard penetrometer on a large amount of samples. The authors have tried to establish relationships between the number of blows per foot and the compressibility of 12 different types of soil ranging from fine sand to clay. The modulus of compressibility thus determined should be regarded as the standard penetration test itself, namely as an approximation which can serve as a guide especially in those cases where undisturbed sampling or other methods of investigation are difficult to perform or take too much time or money. The influence of pore pressure is investigated. The authors deserve merit for the extensive testing of 225 samples which enabled them to apply statistical methods in finding the desired correlations.

It may be concluded from the contributions that the penetration tests are becoming of great importance. It needs no emphasize that the growing use of the cone penetrometer all over the world asks for further research on the interpretation of the results. So far the cone penetrometer has been used mainly for the following purposes :

(a) determination of bearing capacity, e.g. for raft foundations and pile foundations;

(b) measuring of density of sands;

(c) determination of shearing resistance;

(d) for reconnaissance, e.g. to detect certain layers as soft clay, in sand, rock, etc.

Future research should be directed on each on these applications.

In situ tests regarding density, shear, permeability, compression, etc.

As a striking example of the application of a non conventional method for soil investigations in the field KUMMENEJE and EIDE (2/12) mention blasting to test sand in situ on its flow slide properties. Four cases are given in which small explosions were provoked at a certain depth in the soil. Pore pressures and settlements were measured and penetration tests with the Dutch penetrometer were performed. The behaviour of the sand during the explosion is regarded to give an indication of the possibility of flow slides. In all the tests a limited liquefaction only occurred around the blasting point; it was concluded that the soil conditions were not favourable to the formation of flow slides.

It would be interesting to know which kind of records during blasting would have been made in regions where flow slides are known to occur, in order to calibrate the applied method. The large settlements, which were measured in the four tests mentioned, indicate a loose packing of the sand and one might wonder whether there at least is some sensitivity for the occurrence of flow slides.

The measured settlements lead the authors to the opinion that compaction of loose sand deposits by blasting seems possible.

A more conventional method to determine in situ properties of soil is described by SÖKJER (2/19). The apparatus he describes, is the helical sounding borer and consists of a screw of some length which is lowered into the ground. The screw consists of two parts: when driven down the parts are pressed together; when withdrawn the upper part of the screw is lifted first, then the lower part follows. In this way the force required to shear off the soil can be measured, from which the shearing resistance is to be derived. When both parts of the soil are above groundlevel the soil can be examined by visual inspection.

The shearing resistance as measured seems to correspond well with the results of vane tests performed at the same sites.

RAEDSCHELDERS and GOELEN (2/14) contribute to the problem of in situ measurement of density and water content of soils by means of radio-isotopes. There is no doubt that the measurement of soil density, simple as it is on principle, constitutes one of the problems in soil mechanics extremely difficult to tackle. Undisturbed sampling may lead to reliable results in cohesive soils; for sand this method is doubtful. The in situ method by means of radio-isotopes therefore deserves all attention.

In the paper tests are given in which the influence of an empty space on the Geiger tube is measured in order to study the way the method is affected by heterogeneity of the soil. From the tests it results that such an empty space can lead to erroneous conclusions if unsufficient thought is given to the possible occurrence of such cavity.

Basic research on the use of radio-active isotopes is given also in the paper of DVORÁK and PETER (2/5). More in particular some effects are studied as loss of activity by radioactive desintegration of the isotope, dispersion, diffusion and loss of energy by radiation. Use of the method in determining ground water flow is discussed.

Permeability in soils and rocks has been studied by CAMBEFORT and MAZIER (2/3), who give interesting details on a method used by them. They emphasize that in rock water seeps through fissures and that permeability thus depends on the occurrence of those fissures; the same phenomenum is observed in alluvial deposits as sand and gravel. This has been confirmed by permeability tests in bore holes from which water was pumped out or in which water was brought in. By measuring the velocity of the water at different heights in the bore hole, the authors succeeded in finding the zones of high permeability.

Another type of in situ tests is described by VIERING (2/20) who presents investigations of vibration in soil and the way it depends on the physical properties of the soil. The well known problem in calculating foundations, on which vibrational forces are exerted, is to avoid any resonant frequency. Therefore it is necessary to determine the natural frequency of the soil. This is usually done with an in situ test, in which a vibrating machine is used. Frequency, amplitude and shape of the surface of contact with the ground can be varied: the vibrations in different points at ground surface are recorded by electronical equipment. From the measurements the author is able to calculate the modulus of elasticity and the angle of shearing resistance of the soil. The tests permit some conclusion regarding the compaction of soil by vibrating machines.

Two contributions are devoted to rock.

In the paper of DVORÁK and PETER (2/5) the results are given of plate loading tests and shear tests in situ on various types of soils and rocks. The type of strain stress relation for rock in a loading test seems to be different from that measured on soil; it is possible however that similar curves would have been found, if the rock had been tested to much higher loads. It is derived from the tests that the results are in good agreement with formulae based on a non-linear stress strain relationship.

Shear tests in situ on coarse grained soils with stones as big as 10-15 cm are worth to be noticed, as sampling of these soils for performing laboratory tests would be extremely difficult.

SERAFIM and LOPES (2/18) report on in situ shear tests and triaxial tests on rock. Special attention is given to the degree of weathering of rock, viz. schists and altered granites. The tests point to a rapid decrease of shearing resistance with increase of the weathering degree; the most weathered rock showed still an angle of shearing resistance $\varphi = 35°$ and some cohesion.

The results obtained with in situ shear tests show remarkable agreement with triaxial tests performed in the laboratory. This leads to the conclusion that in situ tests are to be preferred, as they are more representative for the formation as a whole, taking into account local disturbances as fissures, etc.

From such tests performed with inclined forces it can be concluded that the ultimate resistance of a foundation against shear increases considerably with the line of action of the exerted force approaching the normal to the surface.

The complete test results are worth to be analyzed by anyone involved in building structures in rock.

Field measurements

The foregoing chapter dealt with in situ tests which aim at the determination of certain properties of soil, as for instance compressibility and shear strength, which properties are to be used as a basis for design and therefore have to be determined at beforehand.

This chapter is devoted to field measurements, to be made during the execution of a work in order to control deformations, pore pressures, etc.

On the third international conference in Zürich 1953, Plantema presented several papers which contained designs of pore pressure and soil pressure meters and an inclinometer for measuring horizontal deformations in the subsoil. Cambefort during the discussions supplied information concerning a similar inclinometer.

KALLSTENIUS and BERGAU (2/10) describe three different inclinometers developed by the Swedish Geotechnical Institute, one of which is a strain gauge inclinometer developed by the Swedish Geotechnical Institute, one of which is a strain gauge inclinometer of very much the same type as described by Plantema and Cambefort.

For measurements in clay a flexible tube with a diameter of 4 cm is installed vertically in the ground, which has appeared to be possible to a depth of 70-90 m already. The inclination is measured with wire resistance strain gauges fixed on a leafspring which is lowered in the tube and bends according to the inclination. The usual sources of disturbance as, temperature differences, etc., are excluded by taking readings at two positions of the spring which differ 180°.

For measurements up to about 4 m depth a mechanical inclinometer is described; a third instrument consists of a pendulum in electrical contact with a micrometer which can be handled remotely from ground service. This apparatus is suitable for long time in place measurements and could be used in a warning system against ground movements in excess of certain values.

Laboratory equipment in the field

To avoid transport of samples and to obtain direct information on the site, field laboratory equipment can be useful.

WARLAM (2/21) designed a triaxial apparatus for field laboratories, which is interesting by its adaption to conditions prevailing at the site of a work, viz. light weight, easy transport operation by one man, use without electrical current, etc. Loads can be applied up to 10 ton on 15 cm diameter samples; the exerted load is measured by a load sensitive tube. A special feature is the reduction of friction of the piston by ball guides.

The same apparatus can be reduced in weight considerably by constructing it of aluminium.

Applied field investigations

Failure of a bridge at severe floods necessitated investigations regarding the scour of various rivers in Natal, South Africa, as reported by KÜHN and WILLIAMS (2/11). The exploration was done by means of wash borings, Dutch penetrometer tests, density logging using gamma rays and short range waves excitated by a special under-water hammer. The borings supply the most reliable information; it is probable however that the penetration tests would also have given more complete indications if only more load (higher than about $2\frac{1}{2}$ ton) has been available. In the given circumstances the penetration test ended in a rather shallow layer of coarse sand and pebbles just above the scouring depth.

For future measurements of river scour automatic level indicators are provided, which start to work at a certain predetermined high water level. The principle of the technique, based on similar work carried out by [Hubbard, 1955], consists of recording the electrical conductivity along several electrodes mounted on a concrete pile at different heights. From laboratory research it is known that this conductivity is different in water, undisturbed sand and moving bed load.

Full scale field tests

During construction of the St. Lawrence Power and Seaway Developments, deposits of sensitive fissured post glacial marine clay were encountered, the shearing properties of which appeared difficult to ascertain by normal sampling and field vane tests. Therefore, as BAZETT, ADAMS and MATYAS (2/1) report, a test trench was made in which the soil was excavated nearly vertically up to depth at which slides occurred.

The results of the effective stress analyses based on the observed field data were compared with vane tests, unconfined compression and triaxial tests. The shear strength determined by the field tests was higher than indicated by the unconfined compression and triaxial tests, but lower than resulted from the vane tests.

The authors rightly state that for complete evaluation of the tests, stress relieve and pore pressure should have been taken into account.

Closure

The recent trend in the development of field measuring technique in soil mechanics, at it is confirmed by the contributions to this Division, seems quite definitely to be in the direction of emphasizing the need of determining fundamental soil properties by direct testing in the field. Disturbance and transport of samples thus can be avoided.

Several field tests of such a kind are at the disposal of the soil engineer. The penetrometer has already found its way. Other field tests are gaining in perfection and popularity.

Apart from perfection of the measuring technique as such, full attention should be given to improve the interpretation of the test results by theory.

Standardization of conventional field tests is equally important.

A drawback of field tests is that it is as a rule impossible to study soil under varying stress-strain conditions. This has to be done in the laboratory.

Therefore equal emphasize should be given to the perfection of the sampling technique.

Sampling in cohesive soils as clay has reached the stage that samples sufficiently undisturbed for practical purposes can be taken. Frictional forces between the sampling tube and the soil sample should be avoided.

Undisturbed sampling of sand is a problem which is not completely solved. Research on that subject should be stimulated.

The question rises whether research on sampling and field measurement technique should not be coordinated in such a way that the various agencies, working on the subject, specialize each on a limited number of problems agreed upon by mutual understanding.

Field measurements during the execution of works can contribute considerably to the development of Soil Mechanics and Foundation Engineering. Care should be taken however that the measurements are made in such a way that they can be correlated with the soil properties, which are necessary to be known and have been found out by testing.

Technique of field measurement and sampling should not be considered as an aim in itself : it is closely related with theory, practice and laboratory research.

Conclusion

La nouvelle tendance du développement de la technique de mesures effectuées sur le terrain par la Mécanique des Sols, confirmée par les communications présentées dans cette Section, souligne la nécessité de déterminer les caractéristiques fondamentales du sol par des essais directs sur place. Le remaniement et le transport des échantillons peuvent être ainsi évités.

Plusieurs essais de ce genre sur le terrain sont à la disposition de l'ingénieur des sols. Le pénétromètre a déjà fait son chemin, et d'autres essais sur place gagnent en perfection et notoriété.

Le perfectionnement de la technique des mesures effectuées mis à part, une attention particulière devrait être portée à l'interprétation, par la théorie, des résultats des essais.

La standardisation des essais sur terrain suivant les théories déjà admises, est également importante.

Les essais sur le terrain présentent l'inconvénient de ne pas permettre généralement l'étude des sols sous des conditions variées de tension-déformation. Ceci doit être fait en laboratoire.

Il faudrait donc rechercher à perfectionner la technique du prélèvement d'échantillons.

La prise d'échantillons dans des sols cohérents comme l'argile est suffisamment au point pour obtenir des échantillons non remaniés. Il faut éviter les forces de friction entre le tube qui sert au prélèvement et l'échantillon du sol recueilli.

Le prélèvement d'échantillons de sable non remanié est un problème qui n'est pas entièrement résolu. Des recherches en ce sens devraient être encouragées.

On se demande si les recherches faites sur le mode de prélèvement d'échantillons, et sur la technique de mesures effectuées sur le terrain, ne gagneraient pas à être coordonnées de manière à ce que les différents organismes s'intéressant à ce sujet, se spécialisent, par entente mutuelle, pour ne traiter chacun qu'un nombre limité de ces problèmes.

Des mesures effectuées sur le terrain pendant l'exécution des travaux, contribueraient considérablement au développement de la Mécanique des Sols et des Travaux de Fondations. Il faudrait s'appliquer cependant à ce que les mesures soient effectuées en corrélation avec les propriétés du sol, qui doivent être nécessairement connues et doivent avoir été déterminées par des essais.

La technique des mesures effectuées sur le terrain et celle du prélèvement d'échantillons ne doivent pas être considérées comme un but en soi : elles sont en relation étroite avec la théorie, la pratique et la recherche en laboratoire.

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