# Techniques of Field Measurement and Sampling

Méthodes pour Mesures sur Place et Prélèvement d'Échantillons

## General Report

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### Introduction

The General Report for Session 3 of the Third International Conference (Turnbull, 1953) in taking into consideration not only the papers submitted to that Conference but also mentioning the most interesting publications on the subject issued from 1948 to 1953 succeeded in presenting, in a very accurate manner, the status and value of the several techniques of field measurement and soil sampling up to the time it was written. The references there collected provide a valuable source of information to any one who wishes to become acquainted with the most recent developments of field measurements and sampling of soils.

Although field techniques in soil mechanics have not ceased to develop, it seems that, since 1953, no major new factual research or publication has become known in this field. So it was decided, in the present Report, not to mention in detail the several techniques already described in the 1953 Report. It will be limited almost completely to comments on the papers presented for discussion in this Division. Publications and techniques developed before 1953 will be mentioned only if necessary for the good understanding of the text, or when they continue to stand as landmarks in the development of the field techniques of soil investigation. Only the principal publications issued since 1953 on the subject of this Division will be mentioned. The list of references is restricted to papers mentioned in this report; papers submitted to the Division are not included in this list but are indicated in the report by the name of their authors. This report is divided in accordance with the nature of papers presented in five parts:

(I) Geological Reconnaissance, Geophysical Methods of Sub-soil Investigations and Field Tests on Rock:
*Field Tests of Rock on Dam Sites*, by A. Dvořák

(II) Soil Exploration and Sampling:
*Undisturbed Sampling Techniques for Sands and Very Soft Clays*, by S. Serota and R. A. Jennings

(III) Penetration Tests
*Experiences with Penetrometers*, by E. Schultze and H. Knausenberger
*Some observations on the Standard Penetration Test and a Co-relation of the Test with a New Penetrometer*, by D. J. Palmer and J. G. Stuart
*Influence of Density on Sounding Results in Dry, Moist, and Saturated Sands*, by G. Plantema
*Measurements of Soil Compressibility* in situ *by Means of the Model Pile Test*, by R. Haefeli and H. B. Fehlmann

(IV) *In situ* Determination of Moisture Content and Soil Densities
*Determination of Moisture Content in Porous Materials by Means of the Relative Humidity inside a Cavity*, by M. Rocha, Ú. Nascimento and E. de Castro
*Field Investigations of Soil Densities and Moisture Contents*, by V. A. Durante, J. L. Kogan, V. I. Ferronsky and S. I. Nosal
*La Mesure* in situ *de la Porosité des Sables*, by H. Cambefort

(V) In situ *Measurement of Permeability, Water and Earth Pressure, Settlement and Deformation*

### Geological Reconnaissance, Geophysical Methods of Sub-soil Investigations and Field Tests on Rock

The importance of geological investigations as a basis for the soil mechanics approach to problems involving extensive areas is being more and more recognized. A sign of that fact is the recent publication by the U.S. Geological Survey (1956) of a collection of maps together with very interesting information about the art of interpreting geological maps for engineering purposes.

However, the main sources of information concerning the application of geological and geophysical methods to the investigations of soils in connection with engineering problems in America remains still the *Berkey Volume on Engineering Geology*, published by the Geological Society of America (1952), and the *Symposium on Surface and Subsurface Reconnaissance*, published by the American Society of Testing Materials (1952).

An excellent book by Gignoux and Barbier (1955), published in Paris, presents a good description of the progress of these investigations in Europe.

Aerial reconnaissance has been, lately, incorporated into the current techniques of geological investigation, but its utilization in problems of soil mechanics seems to have been restricted to a few areas of exceptional extent and applied only by the greater organizations which are mostly government controlled. In connection with common projects this method does not seem to have been applied.

A great advance in the knowledge of the relations between geological condition and soil properties was made with Professor Terzaghi's (1955) paper *Influence of Geological Factors on the Engineering Properties of Sediments* in which a definite step in the correlation between geological character and physical properties of sedimentary soils is made. It is plainly demonstrated that the physical and mechanical behaviour of a soil is directly related to its petrographical characteristics, its facies of sedimentation and its evolution. The references made in the paper provide a list of the main publications on the subject up until 1955.

Unfortunately nothing similar was published in connection with the properties of residual soils, which probably are much more related to geological characteristics than the sedimentary. Many data have been collected in correlation with the subject mainly in the southern United States (SOWERS, 1954) and in Brazil (VARGAS, 1953), but publications till now have only covered partial aspects of the problem.

For the *in situ* determination of the resistance, elastic properties and loss of water of rock, field tests have been developed. In that connection pressure tests in galleries for the determination of the modulus of elasticity of rock, mainly in connection with tunnel and dam construction, have been conducted in France (MAYER, 1953), Italy (OBERTI and VERDUCCI, 1949), Portugal (ROCHA and SERAFIM, 1954), and Brazil (PICHLER and DE CAMPOS).

Dvořák (2/3) presents an interesting paper on *Field tests of Rocks on Dam Sites* where he refers particularly to the determination of the angle of internal friction and cohesion, using Terzaghi's theory of bearing capacity of soils, by means of a direct shear test made with a reinforced concrete block, and loading tests using test plates of different sizes. All tests were performed in galleries excavated through soft rock, and applying loads up to 200 ton. It is however questionable if Terzaghi's bearing capacity formulae can be applied to any type of rock.

The same paper presents also some values of the dynamic moduli of elasticity obtained from seismic tests. The paper mentions SÜSSTRUNK (1953) as a reference for the description of the test. However the values obtained by the author are rather low as compared with those presented by Süsstrunk. Several similar tests made by Pickler and de Campos in Brazil are in agreement with those presented by Süsstrunk.

The author defines a modulus of deformation, obtained by plotting the first loading part of the stress–strain curve. This modulus compared with the modulus of elasticity, computed from the rebound branch of the curve, constitutes an interesting indication of the amount of fissures in the rock. This is also estimated by the measurement of the absorption of the frequency of an elastic wave which is caused to propagate through the rock by an explosion.

**Soil Exploration and Sampling**

The lecture delivered by TERZAGHI (1953) at the Third International Conference 'Fifty Years of Sub-soil Exploration' outlined the status of the art of soil exploration and sampling, at that date, and brilliantly summarized the history of sounding and sampling techniques for engineering purposes from its beginning to 1953.

The lecturer made it clear that securing clay samples in a relatively undisturbed state was the first and main line of improvement in the methods of sub-soil exploration while the invention of the various procedures for recovery of undisturbed sand samples was the second main line of improvement. In 1948 the art of obtaining clay samples had reached a state of maturity with the publication of HVORSLEV's (1949) book on subsurface exploration and sampling, which constitutes a definite landmark in such developments. From that date all the progress in this field is in the improvement of details of sampling devices and techniques. Mention is to be made of the investigations carried out by NIXON (1954) with reference to the compressed air sand sampler, developed by BISHOP (1948); also the OSTERBERG (1952) piston sampler deserves mention as a real advance in the art of obtaining soil samples.

An interesting paper is presented by Serota and Jennings (2/8) on *Undisturbed Sampling Techniques for Sands and Very Soft Clays*. They describe three types of samplers: a sand sampler; a 4 in. diameter long sampler, consisting of three sample tubes coupled together; and a 4 in. diameter long stationary piston sampler. The sand sampler is a very interesting simplification of the Bishop sand sampler, using the same compressed air principle for retaining the sample in the tube. It consists of a $2\frac{3}{8}$ in. diameter thin-walled brass tube which is forced into the sand by means of boring rods. Air is pumped through an air line which leads to a hole in the side of the sampler 1 in. above the cutting edge. Sand grains are bound together by the air–water surface produced at the bottom of the sample by the compressed air, which helps the sample to keep in the sampler tube. No objective data are given to permit a judgment of the quality of samples taken with the sand sampler described.

Bearing in mind that samples of very soft clays taken as conventional long samples have their tops and bottoms disturbed, the authors describe a sampler consisting of three sample tubes coupled together to be used in this type of material. The extreme sample tubes are discarded and the sample in the intermediate one is preserved for testing. The authors state that with this device it was possible to sample sensitive clays at moisture contents above the liquid limit and shear strengths between 100 to 200 lb./sq. ft. without appreciable disturbance.

In the same paper a stationary piston sampler is described which was designed by the senior author in collaboration with Professor Skempton's staff. The sampling barrel was made up of three standard 4 in. diameter tubes, two 18 in. long and one 8 in. long, coupled to a cutting shoe of slightly smaller diameter, capable of containing entirely the piston when lowered to the bottom of the sampler. Only the soil in the middle tube is preserved for testing. Details of sampling at two sites are described in the paper showing the efficiency of the two latter samplers when used in sampling sensitive normally consolidated clays. In order to compare the quality of each type of sampling the authors plot curves in which they show the measured relation $c/p$ (where $c$ is cohesion and $p$ the consolidation pressure) against the predicted $c/p$ relation according to a relationship found by SKEMPTON and HENKEL (1953), between $c/p$ and the PI. This procedure for judging the quality of samples is based on the assumption that the same relationship is valid for all clays, and that the discrepancies from the average values in the $c/p$ *versus* PI relation are sufficiently small.

The difficulties and high prices of operation for securing undisturbed samples from bore holes has kept the attention of soil specialists towards the development of less expensive methods for obtaining soil characteristics.

As in the sampling of clays the main object is to determine the shearing strength in the undisturbed state, the techniques of thin-walled small diameter samples (tube-sample borings), which allow securing of continuous small diameter cylindrical samples, fit for unconfined compressive strength tests, and vane-borers designed to determine the shear resistance of the clay by the rotation of vanes attached to vertical shafts, were developed almost to perfection. However both methods can only be used when the sub-soil conditions are well defined. It is also widely known that thin-walled tube samples, in many events, give smaller compressive strength than the clay actually has, on account of disturbance, and that the shear resistances observed in the same test do not always correspond exactly to a quick undrained test. Also progressive failure in stiff or brittle clay is a source of mis-interpretation of vane test results.

During the past few years field vane tests have been largely utilized in Europe, in connection with the *in situ* determination of shear strength of soft sensitive clays. Correlation of results of vane tests with shear resistance of clays measured in the laboratory has been described in many papers in Europe. To a lesser extent these tests have been utilized also in the United States (BRYCE BENNET and MECHAM, 1953; GRAY, 1955). A few American publications discuss correlation of results of vane with other tests. All these observers agree that strengths as measured by the vane tests were about 2 to 3 times greater than those obtained from unconfined compression tests on undisturbed samples. Results of correlation between vane tests and triaxial compression are still too controversial to lead to any definite conclusion. Skempton's and Henkel's conclusions in their paper presented to the Third Conference are still justified.

**Penetration Tests**

For the determination of the relative density of sands and consistency of clays and its correlation with bearing capacity and compressibility, penetration tests are being widely used instead of securing undisturbed samples on account of their lower cost and facility of operation. Penetration tests can be classified in two main groups: static and dynamic tests. In most of the countries of Europe it seems that the static cone penetration has the preference; in both North and South Americas the dynamic penetration test dominates. Both procedures were described and discussed, in summary, by Dr. Terzaghi in his lecture at the Third Conference. Details of both methods can be found in the references made in that lecture.

A correlation between dynamic and static penetration with the relative density of sands and the bearing capacity of foundation on much soils was attempted by MEYERHOF (1956) taking into account data from several investigations from all over the world. In spite of the preoccupation of using as much experimental data as possible many of the correlations obtained by Meyerhof are based on mere suggestions and not on experimental data. A statistical study of the correlation between penetration tests made in Brazil (similar to standard penetration tests described by Terzaghi and Peck) and the bearing capacity of sands and clays has shown that the average deviation from the most probable value can be as high as 100 per cent (SILVA LEME, 1953). Brazil is probably one of the countries where penetration tests are most widely used for the design of building foundations. Studying the correlation between standard penetration tests and allowable loads in foundations for buildings in Brazil, MACHADO and MAGALHÃES (1955) have concluded that it is only correct to state that the higher the penetration resistance the higher will be the allowable load on the foundation; however, the bearing capacity for soils of small penetration resistance is not necessarily low. So the indiscriminate use of correlations between penetration resistance and bearing capacity, as advised in many recent soil mechanics textbooks, may often lead to extremely conservative and expensive solutions. No attempt should ever be made to use these tests without knowledge of the soil conditions.

A very interesting account of the results of experience is presented by Schultze and Knausenberger (2/9). The authors describe comparative tests which have been performed with three static and six dynamic penetrometers of different types, compare their behaviour, and discuss the advantages of each apparatus in relation to soil conditions at 20 different sites. A very valuable analysis of the behaviour of the static and dynamic penetrometers in gravel, silt, clay, and organic soils is made. Such an analysis forms a basis for the understanding of the scattering of values observed in the attempts made to correlate penetration resistance with other soil characteristics without taking into consideration the nature of the soil. Comparing static with dynamic penetration tests the authors confirmed the results obtained by MEYERHOF (1956), according to which the cone resistance (in kg/cm$^2$) is about four times the number of blows of the standard penetration test. They found also that for clays that ratio is about 2. In summary they found the static cone penetration test the closest to static loading condition, but they require a heavy counterweight for most soils which renders its use difficult and troublesome. The standard penetration test made inside a bore hole is the most reliable dynamic test and represents a satisfactory substitute for the static test. The paper presents an excellent systematically arranged set of data for the good interpretation of penetration test results.

Palmer and Stuart (2/5) discuss the use of standard penetration tests in sands and gravels, and suggest the use of a cone which is to be attached to the split-spoon sampler closing its end. A very good analysis of the effect of variations in the results of standard penetration tests in the field is made, including observations on the varying lengths of boring rods, drops of hammer, upward seepage and extrapolation of results. Comparing results obtained with the open sampler and the cone the authors found both penetrometers gave results of the same order, and state reasons for the preference of the new penetrometer. A correlation graph shows a variation between both tests of $\pm$ 25 per cent. The authors observe that the allowable pressures for foundation on gravel estimated by correlation with standard penetration tests given by PECK, HANSON and THORNBURN (1953) are lower than those observed in plate bearing tests or commonly expected, and suggest an increase of at least 60 per cent on the allowable pressures on gravel when predicted as if for sands. This statement seems to be in agreement with data observed by many investigators all over the world.

Plantema (2/6) describes in an interesting paper the results of penetration tests in five types of sands in several conditions of compaction in dry, moist and saturated states. The sounding resistance was found to increase proportionally with depth. The author defines 'the sounding inclination', as the slope of a straight line in a graph showing sounding resistance (in kg/cm$^2$) against depth (in cm). The graph is drawn on such a scale that for a sounding resistance of 10 kg/cm$^2$ the corresponding depth, for a line with an inclination of 45 degrees, should be 10 cm. The angle $\alpha$, thus defined, serves as a measurement of the penetration resistance for the sands in several states of compaction and water conditions. As a conclusion of his observations the author states that the described method appears to be accurate for the determination of dry density of sand beds. The inclination $\alpha$, for equal dry density, was found to be greater for the moist sand and smaller for the dry sand; the saturated sand showing an intermediate value for $\alpha$. Unfortunately no conclusions were made from this experiment, which could lead to some method of estimation of relative density and angle of internal friction from results of cone and standard penetration tests.

Haefeli and Fehlmann (2/4) present a paper describing a model pile test by means of which the authors planned to determine the modulus of compressibility of the soil. The described model test, on account of the form of the model pile, its dimensions and the procedures to run the test can be classified in the group of 'static penetration tests'. A correlation between settlement of the model pile and the 'modulus of compressibility' is theoretically established by means of considerations based on Boussinesq's equations. Laboratory tests, using the cone test to determine consolidation pressures of the soil into which penetration of the pile was made, were performed to check the theoretical relation above mentioned. The authors state that the method is still in a state of development and further tests are planned.

***In situ* Determination of Moisture Contents and Soil Densities**

The determination of moisture contents and soil densities by surface or boring sampling and laboratory tests is found by many investigators to be slow and expensive, thus the interest in developing methods to permit the continuous determination of water content in soils has increased lately.

Describing a very interesting method for solving the problem of continuous and long-time measurement of moisture contents in porous materials, Rocha, Nascimento, and de Castro (2/7) have presented a paper in which they report a research under progress at the Laboratório Nacional de Engenharia

Civil, in Lisbon, on the determination of moisture content in soils or concrete by means of the measurement of the relative humidity, based on the fact that relative humidity inside a cavity in porous materials is a function of the moisture content of the material which forms the walls of the cavity. Thus they are trying to use a vibration wire hygrometric cell placed inside cavities in the materials and to obtain the relative humidity by using previously determined curves relating moisture content of the material with relative humidity of its neighbourhood. Unfortunately the paper is related to the laboratory investigations and calibration of apparatus and does not mention any attempt actually to measure the moisture content of a mass of soil in the field or even in the laboratory. The real difficulties of the procedure will be probably in this last phase of the research.

A very interesting paper on field investigation of soil densities and moisture content is presented by Durante, Kogan, Ferronsky and Nosal (2/2), of several agencies of the Russian government. The paper starts by describing an investigation of the densities of sand deposits, sampled after freezing it to a depth of 25 m. Correlation between granulometric composition, densities, and air content is established. Then an investigation of correlation between penetration tests and densities is described. During this investigation it was observed that the sand had a sort of natural structure which was supposed to be responsible for a high penetration resistance observed. In sand fills where the natural structure was absent penetration resistances were lower. The results of these investigations are very interesting, and constitute a real contribution for the correlation between penetration resistance and density and granulometric composition of sands. Unfortunately the penetrometer used and details of its utilization are not described.

The second part of the paper deals with the use of a method for determination of densities and moisture contents of sands by gamma rays. Since the Symposium on the use of radioisotopes in soil mechanics promoted by the A.S.T.M. (1952), interest in the use of radioactive materials in the determination of moisture contents and densities of soils has largely increased. An interesting application of this method in the subgrade of the San Francisco Airport pavement was described by HORONJEFF and GOLDBERG (1953). In short, the method consists in the use of a neutron source for determination of the moisture content and a gamma ray source for density determination. The 'fast neutrons' emitted by the neutron source are changed into 'slow neutrons' when they collide with hydrogen atoms. Some of them return to the apparatus and are counted; the count is correlated with the water content of the soil. The density determination is based on the known fact that the gamma rays are scattered by atoms in their path so the reflection of the rays can measure the density of the soil.

A 'radioactive fork' designed for controlling soil densities in accessible places is described. This apparatus is supposed to give good results in controlling densities of fills compacted layer by layer. However little practical information is given in the paper about the performance of the apparatus in the field. A field experience made in holes filled with sandy soil where two 2 in. pipes were sunk 0·5 m apart and a radiation source and a Geiger counter lowered simultaneously in each hole is described. Undisturbed samples were taken and their densities determined in the laboratory. The authors give no information about the comparison of densities determined by gamma rays with those determined directly.

An interesting application of the electrical logging method, already currently used in drilling for oil, is described by Cambefort (2/1), for the *in situ* determination of porosity of sands. The author presents an empirical formula relating porosity, resistivity of the soil surrounding a drilled hole and resistivity of the liquid in the voids of the soil. Measurement of the resistivity of the soil is done by means of an apparatus which is lowered into the boring. No correlation between electrical and direct determination of porosity is mentioned.

### *In situ* Measurement of Permeability, Water and Earth Presure, Settlement and Deformation

Unfortunately no paper was presented to this Division describing the techniques of *in situ* measurement of permeability, water and earth pressure, settlement and deformation. However some of the subjects under this heading are so important for the development of soil mechanics and the solution of engineering problems that they deserve mentioning.

There is a growing interest in the development of new devices for measuring water pressures due to the necessity of measuring neutral pressures in earth dams. The three main types of piezometers, viz. the CASAGRANDE (1949), the U.S. Bureau of Reclamation (1950) and the Plantema, are still in continuous improvement. The chief scope of the investigations is the increase of the sensitivity and of the durability of the cell when buried into the ground. In 1956 PENMAN described an apparatus developed at the Building Research Station which has been used to measure pore pressures at 14 different sites during the last five years. The apparatus follows the principle of that used by the U.S. Bureau of Reclamation. Excellent performance is reported in the paper.

Many laboratories are at present engaged in trying to improve the electrical cell described for the first time by Plantema at the Second Conference in Rotterdam. Up till now the durability of the electrical cell has been questionable, however its simplicity of operation is such that improvements of its durability are highly desirable.

The observation of settlement of foundations and earth structures constitutes one of the main lines of investigation in soil mechanics. The results of these observations are still dispersed in many articles, and only in a few instances have they been gathered together and properly digested, as Skempton in 1956 did for the settlements of tall buildings. Recent advances in the observation of settlement of foundations consist mainly in the improvement of the Terzaghi water-level, for more accurate and quick measurements, and in the development of methods for the use of precision optical levels. Also details on the installation of bench marks have been improved recently, but there is a scarcity of published papers on these questions.

### Closure and Proposals for Discussion

Judging from the papers presented to this Division and from the principal publications issued since the last Conference it can be stated that no major development has been made in the various techniques of soil exploration and sampling or in the *in situ* measurements of permeability, water and earth pressure, settlement and deformation.

However, the understanding of the convenience of the use of geological, geomorphological, aerial photographs and geophysical reconnaissance methods has been pushed forward, and has contributed to a better approach of the field investigations for engineering problems.

The existence of a large number of different types of devices for measuring penetration resistance of the soil can be considered as harmful to the development of the knowledge of soil properties. In most cases the differences between them are limited to construction details, which are irrelevant to the practical utilization of penetrometers, but which introduce differences in the values obtained. Such a variety of devices leads to values of penetration resistance which cannot be compared among themselves. The same remarks can be applied to the differences in the methods of measuring penetration resistance. It is most desirable that only a few standard procedures and devices should be adopted by the several agencies engaged in soil exploration, so that the results of a field investigation can be properly understood and utilized by any person interested in such determinations.

Much attention has been given to the research on the utilization of radio-activity of isotopes and gamma rays in the *in situ* determination of soil densities and moisture content. Results of field investigations are, however, still insufficient for a conclusion to be drawn of the convenience of the method for current applications.

It is suggested that during the discussion preference should be given to the following topics which seem to be of greatest interest:

(1) Correlation of test results of several types of penetrometers in order to establish the possibility of selection of a few types of penetration resistance methods for recommended use.

(2) Correlation between density, water conditions and bearing capacity and the penetration resistance of sands.

(3) Field investigations of soil densities and moisture content.

(4) Advantages, fields of application and performances of the several types of apparatus and methods of measurement of neutral pressures in earth structures.

### Conclusion et Propositions pour la Discussion

Si l'on fait la synthèse des communications présentées dans cette division et des articles publiés depuis la dernière conférence, on peut dire qu'il n'y a pas eu de développement dans les diverses techniques de prospection et de carottage, dans les mesures *in situ* de la perméabilité de la pression des sols ou de celles de la pression interstitielle et enfin dans la mesure des tassements et déformations.

Cependant, on saisit de plus en plus l'intérêt de l'utilisation des moyens de reconnaissance géologique, géomorphologique, géophysique et aérophotographique et ceci permet à l'ingénieur d'aborder dans de meilleures conditions les problèmes de terrains.

L'existence d'un grand nombre d'appareils de mesure de résistance des sols par pénétration nuit à la connaissance de leurs propriétés. Dans la plupart des cas, les appareils ne diffèrent que par des détails de construction, sans rapport avec la pratique des pénétromètres, mais conduisant à des différences dans les enregistrements. Une telle variété d'appareils ne permet donc pas de comparaisons valables. Les mêmes remarques s'appliquent d'ailleurs aux méthodes mêmes de mesures. Il est donc très désirable que seulement quelques méthodes et appareils soient adoptés par ceux qui s'intéressent à la prospection des sols, de façon à rendre les résultats plus compréhensibles à quiconque.

Il faut noter aussi que beaucoup de recherches ont été consacrées à l'utilisation des isotopes radioactifs et des rayons gamma pour la détermination *in situ* de la densité des sols et de la teneur en eau. Mais les résultats expérimentaux ne permettent pas encore de dire si la méthode convient pour les applications courantes.

Le rapporteur suggère que la discussion porte de préférence sur les points suivants dont l'intérêt paraît le plus marquant:

(1) Corrélation des résultats expérimentaux donnés par les pénétromètres, en vue de retenir et recommander quelques méthodes de mesure de résistance des sols par pénétration.

(2) Relation entre la densité, la position de l'eau, la force portante et la résistance à la pénétration dans les sables.

(3) Mesures *in situ* de la densité des sols et de la teneur en eau.

(4) Avantages, champ d'application et performances de quelques appareils et méthodes de mesure des pressions au repos dans les massifs.

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