SECTION XII

SUBJECTS OF A GENERAL CHARACTER

GENERAL REPORT

E. DE BEER (Belgium)

XIIa: CLASSIFICATION OF SOILS

Some papers considered the possible international cooperation especially in view of arriving at an internationally accepted classification of soils.

This first short abstract of the submitted papers concerning classification of soils will be given.

1) A first report concerning this subject is that of the Division of Soils, Council for Scientific and Industrial Research, Adelaïde, South Australia. In that report it is suggested that in view of the lack of uniformity in accepted usages of terms for colour, texture and structure of soils, international agreement for such description terms, among engineers as well as soil scientists would be desirable.

No indications as to the means to solve these problems are given.

On the other hand the same report proposes that agreement should be reached on the question of adopting 2 microns as the upper limit for the effective diameter of clay. The upper limit for silt is admitted to be less important, but should nevertheless also be considered.

2) A second report is from Poland. Mr. Pietkowski considers it as a matter of primordial importance as a first step for international cooperation to have a unified classification and denomination of soils. Otherwise comparing and profiting of similar tests and experience is very difficult if not at al impossible.

The bases on which the Polish Committee of Standards has put its classification are: granulometric composition and consistency or density.

In the Polish opinion the content of particles < 0,002 mm does not present a characteristic feature for general classification but so does indeed the percentage of particles < 0,006 mm.

For differentiating between clay and loam the author considers the fraction "a" less than 2 microns, and the fraction "b" located between 2 and 6 microns.

For instance a clay is a soil containing more than 30% particles less than 2 microns. The denomination of the soils is exclusively based on the mechanical analysis but attention is paid on the ratio of the different fractions.

Next its denomination, the soil classification is supplemented by the consistency, for cohesive soils, and by the relative density for cohesionless soils. The consistency is determined by comparing the natural water content to the Atterberg limits, the relative density by comparing the void index to its maximum and minimum values.

3) A third paper concerning the subject was submitted by the Melbourne and Metropolitan Board of Works-Australia.

This paper suggests that our conference might consider initiating a uniform system of soil identification and classification.

The essential functions of a uniform system should be:

(a) To provide a standard of nomenclature for soil identification.

(b) To assist in condensing experience with soil behaviour. A suitable system should be:

(a) Acceptable to all soil workers, e.g. engineers, agricultural scientists, and geologists.

(b) Simple and convenient in use.

(c) Capable of detailed expansion for special purposes without affecting the basic systems.

Any single system which met these basic requirements would probably be too complex for convenient use. An alternative would be a two-stage system providing:

(a) Simple system of field identification.

(b) Detailed functional classification for each major branch of soils work. These could each be developed by the appropriate professional association and its details exchanged with the other soil workers. Workers in any one field, e.g. civil engineering, would operate with that particular functional classification, but would have the other systems for reference when exchanging data.

For the field identification, two systems are available:

(a) The modified descriptive system adopted by the Division of Soils, C.S.I.R. Australia, or

(b) the field section of the AC classification.

The modified descriptive system uses standardized terminology, but is essentially a field identification system. The ultimate test of the description of any soil is the majority verdict of experienced soil surveyors. To keep such opinions up to date and uniform, periodic conferences are held for interested parties, general descriptions are prepared, and comparisons are made between the classified types and their simple physical properties. All such descriptive terms and standards are subordinate to field usage and are periodically amended where necessary. This method has the advantages that it has been, and still is, the most widely used identification system, it is very simple and convenient in use, and it is based on field observations and was developed solely for field use.

The AC classification field section is more complex and less flexible than the simpler system. In addition, its use is much more restricted and as such it would be harder to reach international agreement on its use.

For the engineering functional classification the alternative systems could be (a) PRA system or (b) AC system.

The PRA system was developed for highways and is therefore limited in its general application. A further disadvantage is the periodical revisions which are being made to bring it more into line with the most modern practice.

The AC system is very widely adopted, following its use by the United States Army. It is simple, easily understood and follows logically from the modified descriptive classification of field identification. As such it is suggested as the most suitable functional classification for civil engineers.

While considering uniformity in the classification, the grainsize scales should be studied. Reasonable acceptance, of the International or a modified International scale would be simple if agreement could be reached on the clay-silt size boundaries. So far 0.02 and 0.05 or 0.06 mm have been suggested, but revision would probably meet with little objection from soil workers.

In conclusion, it is recommended that the field identification and classification system should consider as a field identification the modified descriptive system, and as a classification, the AC system.

The A.C. system is not only based on the mechanical analysis but also on the Atterberg limits.

The paper of the Melbourne Board of Works is limited to the denomination of soils, and does not take into account neither the consistency nor the relative density.

4) A fourth paper concerning the same subject comes from the State Rivers and Water Supply Commission, Victoria, Australia. The particle size distribution curve is thought to provide the ideal basis for a classification of soils for engineering purposes. It is, therefore, proposed to represent this curve by two components: namely, the maximum size of particle in the soil and the area enclosed by the curve from the largest down to the smallest particle present in the soil, which then supply the complete classification of the particular soil under consideration. This is believed to provide a fundamental characteristic of each soil with which other physical properties can be correlated.

The least diameter considered is 1,12 . 10^{-5} mm. In this paper it is not attempted to give a name to soils. A sample is now characterized by two numbers.

The consistency and the relative density are not considered.

5) A fifth paper comes from R.R. Proctor. Proctor first draws the attention on the fact that it is not possible to correlate the structural properties of a soil with a denomination as sand, clay etc. of a soil, because in that denomination nothing is said concerning the density or the consistency. It is not possible to complete the denomination by adding an adjective, such as loose, dense ... etc., describing the density, because no two persons will use the same word in the same sense.

The soil classification factors proposed by Proctor are determined from field- and laboratory tests similar to those customarily made in connection with dam construction. Is measured in the field: the moist density of the soil in place. Are determined in the laboratory, the natural moisture content, the natural dry density, the Proctor dry weight curve, and the Proctor penetration resistance curve, the specific gravity, and the percentage of particles less than 74 microns. The characteristics on which the classification proposed by Proctor is based, are:

- soil dry weight in place
- indicated saturated penetration resistance in place
- soil dry weight for 300 lb per sq. in. indicated saturated penetration resistance
- moisture content for complete saturation at an indicated saturated penetration resistance of 300 lb per sq. in.
- percentage passing the no 200 sieve
- the specific gravity
- the percentage retained on no 4 screen.

Next the reports mentioned, there are two summaries, one of Mr. Dowell of the Texas State Highway Department and one of Prof. Burmister.

Mr. Dowell considers only the subgrade and base soils for highways and suggests that they should be classified on the basis of the shearing strength.

At the first sight all foregoing suggestions seem rather contradictory. To put more order in it, we have to find a key, and therefore we must clearly enunciate the aim which is pursued.

This is clearly done in the paper of Mr. Burmister.

1°) First of all there is the problem of examining and identifying soils in the field as positively and accurately as possible. For this first identification it is impossible to impose difficult tests of long duration. Of course this identification is not necessarily complete or even exact. Therefore only general indications can be given about the examinations to be performed, and properties to be detected in the field.

The Australian Division of Soils gives some suggestions about this field identification. As most of the countries have instructions concerning this field identification, and as this identification is essentially approximative, one can ask the question if a kind of international manual of recommendation for field identification is necessary.

2°) Second, - as stated by Prof. Burmister - the soils should be given descriptive names, based upon a common language of description of soils, which will convey a definite meaning to one who has not had the benefit of examing the soils at first hand. The descriptive names of soils should be sufficiently accurate and precise, and expressed in simple engineering and technical terms, so that they can be readily understood by all who wish to use the information on the soils. The aim of this second step is to dispose of simple words, with a clear meaning, thus allowing an easy speaking and writing. It should not be pretty to read a report, in which is always spoken about the soil 12-170-3, etc..... Also in conversation this would be very difficult. Thus naturally there is spoken of sand, gravel, clay, or silty sand. The second step has only the aim of a simple language, not to give all exact informations about all characteristics of the soil.

Thus it is only necessary to give a clear and mathematical definition of some words of the common language, taking care that the definition covers, for the great majority of the cases, the common sense given to the word.

A first attempt to define the common words was based on the mechanical analysis. The granulometric diagram was dividid in a certain number of fractions, and a name was given to these fractions. Of course this is but one of the aspects of the problem.

In fact it seems highly desirable that an International definition of some common words should be given, and that an international division of the granulometric diagram should be adopted.

If for pure sands the definition can be based on the mechanical analysis, it seems that for silt, loam and clay, and of course for peat and marl other properties must also be taken into account, for instance plasticity as done by Prof. Casagrande, or some chemical or mineralogical composition.

Thus the following can be made: "The 2nd International Conference of Soil Mechanics express the wish that an international definition should be given to some soil names of the common language".

As already stated, even a very clearly defined soil name can not give information about all the properties of the soil considered. For instance, as there is spoken of Mr. Huizinga, General Secretary of this Conference, this person is clearly defined, and no mistake with another person is possible. Nevertheless with that only identification, you know nothing about his physical and mental qualities.

Thus, if we will know these qualities, we not only must have the name of the person, but some additional informations.
For communicating the experience obtained in a certain case this is very important. For this 3rd aim it is not sufficient to give the name of the soil, but also the numerical data about all the properties which play a role in the communicated experience are necessary.

Now reading the contributions, it seems that the authors have the meaning that the properties to be dealt with, can be limited to a certain number:

a) Mr. Pietkowski suggests that it is sufficient to give the name, based on certain data of the mechanical analysis, and the consistencity or relative density, depending on the cohesive character of the soils.
b) Mr. Proctor suggest that it is sufficient to communicate
   - the soil's dry weight in place
   - the indicated saturated penetration resistance in place
   - the soil dry weight for 300 lb per sq.in. indicated saturated penetration resistance
   - the moisture content for complete saturation at an indicated saturated penetration resistance of 300 lb per sq.in.
   - the percentage passing the no 200 sieve
   - the specific gravity
   - the percentage retained on the no 4 screen.

All these informations although very valuable and generally necessary, are not always sufficient.

Thus it seems better not to limitate the properties to be communicated, to those given by Mr. Pietkowski or by Mr. Proctor, but to consider them only as minimum requirements. The proposed conclusion is: "The 2nd International Conference on Soil Mechanics draws the attention to the fact that in communicating the experience obtained in a certain case, not only the name of the soil should be given, but also the figures concerning all the properties involved in the experience. At least information about the consistency of cohesive soils, and the density of cohesionless soils shall be given".

XIIb : SURVEY OF THE EXISTING INSTITUTIONS AND INDIVIDUAL WORKERS IN THE FIELD OF SOIL MECHANICS.

Thirty (30) contributions were received from different official- and private laboratories in South-Africa, Belgium, Brasil (3), Tscheco-Slovakia, Denmark, Great Britain (15), Switzerland; Hungary, Sweden, U.S.A. (2), Spain, India, Australia.

There are also summaries of Argentine, Germany, Mexico, Venezuela and the Netherlands.

Most of these contributions mention the type of organization of the laboratory, the composition of the technical staff, the kind of the laboratory- and field equipment. Several laboratories are almost only concerned with teaching and research, others are especially organized for practical tests. In most countries, for instance Sweden, Switzerland, Denmark, Belgium, the main laboratories are state institutions, whose activity covers not only the field of research, but also the complete field of all practical problems met in the country.

Besides the state institutions, which are more or less self supporting, there exist in most countries university-laboratories and laboratories belonging to private companies and to individuals.

The latter are very numerous in England; fifteen different laboratories of that country sent a contribution to the Conference.

It can be worthwhile to notice that most of the laboratories were created in the latter thirties.

A very valuable paper was submitted by Prof. Tschebotarioff and by Prof. Winterkorn, concerning the organization of the teaching and the research in the field of Soil Mechanics at the Princeton University. From that contribution is clearly seen the outstanding interest given in the University teaching programs of the United States to Soil Mechanics and Foundation Engineering. It is worthwhile to notice that in the fourth year every civil engineer has to follow a course on soil mechnics, of 45 hours and has to spend in the laboratory also 45 hours. As this fact is not special to the Princeton University, but is typical for most of the American universities, the wish may be expressed that in a near future all European universities will follow this example, and spend more attention in teaching Soil Mechanics than is actually the case.

The American Society for Testing Materials submitted a report concerning its activity in soil testing and research.

As all the contributions of section XIIb are very useful information concerning the existence, organization, field of working, and special research of many laboratories, it could be worthwhile to publish them together with the reports of the other sections which were introduced too late and for that reason have not been included in the first six volumes of the proceedings.

XIIc : NATIONAL EXPOSITION OF THE LATEST DEVELOPMENT AND IDEAS IN THE SPHERE OF SOIL MECHANICS WITH A REPORT OF LITERATURE.

In this section a first paper was submitted by the British National Committee on Soil Mechanics. The rapid growth of Soil Mechanics in Great Britain started in 1937 after the Harvard Conference on Soil Mechanics. Since 1937 the British laboratories were especially concerned with problems relating to clay soils. In this connection mention may be made of the portable compression apparatus which was developed for the field and laboratory measurement of unconfined compression strength.

In Great Britain many problems arise in relation to the stability of cutting and retaining walls concerned with the so called "stiff-fissured" clays.

Another valuable contribution of Great-Britain is to have drawn the attention to the effect of seasonal variation in moisture content of clays and the effect of trees on the behaviour of shallow foundations.

The humid climate of England introduces special considerations in regard to the construction of earth works. As the rainfall is spread more or less uniformly over the whole year, it is difficult to maintain close control over the water content during construction. Thus studies were made to assess the applicability of U. S. methods of soil compaction and soil stabilization to the rainfall conditions in Great Britain.

It is worthwhile to notice that the same climatic conditions prevail more or less for a big part of Western Europe.

The second paper of this section was submitted by Canada. In this country also Soil Mechanics started growing after the 1936 Harvard Conference. Special problems treated by the Canadian technicists are : glacial silts of the northern regions and permafrost, which means, permanently frozen ground. Part of the permafrost problems are those concerned with "muskeg" a soil of organic nature.

In all Universities of Canada a course on Soil Mechanics is given to all undergraduates for Civil Engineering.

In Canada exist a Soil and Snow Mechanics Committee. The association of Soil and Snow Mechanics has been found to be essential, it is reflected in the similar association of the subjects in Swiss investigation.

A third paper of this section is a comprehensive report on the Earth Materials Laboratories in the U.S.A. submitted by the subcommittee 3 of the U.S. National Committee. There are actually in the States 144 institutions actively participating in the field of Soil Mechanics for teaching, design, construction, or consulting purposes.

The report gives a detailed discussion of the testing equipment and the techniques of the American laboratories. The mechanical analysis is performed by screening down tot 74 microns and by the hydrometer analysis for the finer particles. Before performing the hydrometer analysis some laboratories first eliminate by wet sieving the particles larger than 74 μ. Other make the analysis on the entire soil matrix. The specific gravity and the moisture limit test are determined by normal techniques. In the compaction test there are only two generally accepted impact methods : the Modified AASHO Standard and the Proctor Standard. Some laboratories are equipped to conduct compaction tests by static load or vibration methods.

The permeability tests are conducted with constant head or with variable head. The testing equipment differs from one laboratory to another.

In the States the California Bearing Ratio test has now a general use. It is an empirical procedure for measuring the relative bearing capacity of subgrades, base course materials, or materials for use in flexible pavements, by a standard penetration method. The load intensity required to produce penetration at a standard rate of a 3 square-inch piston into a carefully controlled sample is compared to the load intensity required to produce a like penetration under similar conditions into a standard, well-graded, crushed rock. Unit load values obtained for various depth of penetration from 0.1 to 0.5 inch into the crushed rock sample are standardized, and the values obtained for the C.B.R. test on any sample are expressed as a percentage of this standard. In practice, the ratio at any 0.1 inch penetration is used, with the values in the first 0.1 inch assuming primary importance. Ratios at any succeeding 0.1 penetration are used less frequently.

Readings are taken at 0.025 inch, 0.050 inch, 0.075 inch, 0.1 inch, 0.2 inch, 0.3 inch, and 0.5 inch.

Most American laboratories are equipped with consolidometers, belonging to one of following types : the cylinder with hollow piston (Terzaghi), fixed ring consolidometers with mushroom piston (Hogentogler), fixed ring (Casagrande), floating ring, and piston with floating ring. The specimen sizes generally vary from 2.0 to 5.0 inches in diameter and from 0.5 to 0.2 inches in thickness.

The direct shear tests are commonly used in the U.S. for determining the resistance of soil to lateral distortion. The normal load is usually maintained constant throughout the test, and the shearing load may be applied in increments at a constant rate, or at a rate which will produce a uniform rate of deformation of the specimen.

The direct shear machines can be divided in box- and double shear machines. 64 of the 144 laboratories have direct shear test equipment.

The triaxial compression test is performed to determine the stress-deformation and strength characteristics of soils which are subjected to shearing stresses. The unconfined compression test is considered as a special application of the triaxial compression test where the applied lateral pressure is zero. The test equipment, test procedures and interpretation of data vary considerably throughout the U.S.

Most investigators prefer to use two testing techniques, one for cohesionless soils and oen for cohesive soils. Two values of test data may be obtained during the shear test. For instance, the angle of internal friction obtained by a completely drained sand specimen is assumed to represent the "true" friction value, while the uncorrected values obtained from tests on sealed specimens of sand or clay provide an "apparent" internal friction value. Some investigators perform all triaxial compression tests in a sealed condition, and observe the pressures built up in the pore fluide.

The applied pressures are then reduced by the amount of the measured pore pressures to obtain the effective particle contact pressures. It is assumed that this correction for pore pressure allows the determination of the "true" shear values.

The present practice of some investigators of cohesive soils is to conduct a "quick" test to determine the shear values when no consolidation is allowed. When consolidation is to be considered, the "consolidated quick" or "slow" tests may be performed.

While some investigators determine the shear value of φ and c, others prefer to use the total shear resistance values for various applied stress conditions.

64 of the 144 U.S. laboratories are equipped with triaxial compression testing devices. The equipment, like the testing techniques,

vary considerably throughout the U.S. In general, the cylindrical specimens are enclosed in air-tight rubber membranes. In the U.S. the upper end of the membrane is free-moving.

The loads are applied in increments at a constant rate, or at a rate which will produce a uniform rate of strain.

Many institutions consider the maximum deviator stress (unit axial stress applied in excess of the chamber pressure) to represent the point of incipient failure for triaxial compression tests. The Bureau of Reclamation recognizes the point of maximum principal stress ratio as the incipient failure point.

The stabilization of soils, by mechanical, physical and electrical means is studied at many U.S. laboratories. The study of seepage is made in several laboratories by means of model studies. Photoelastic studies are also performed in some places.

Field bearing tests are performed, especially in view of road and airfield constructions. The loaded plates are rigid and circular, and their size depends on the tire imprint area of the heaviest vehicle to which the road or runway may be exposed.

The Waterways Experiment Station (Vicksburg) uses a cone-penetrometer to make rapid readings in soft soils to a depth of 3 feet. The readings are an index of the shearing resistance of the soil, and they are being correlated empirically with ability of the soil to pass military vehicles.

A paper submitted by the National Committee for India indicates the following inventions and ideas in the sphere of soil mechanics:

1) an improvement in the Proctor apparatus consisting in a special device for assuring the verticality of the needle;
2) the Albot compacting cylinder is preferred to the Proctor apparatus;
3) a method of mixing wet sand and gravel with bitumen for making roads in wet weather;
4) stabilization of soil with cement, with pectin and tannin, with minor forest products, with metallic soap and with oil.

Further resea ch was effected on the following subjects:

1) effect of electrolytes and binders on the density and bearing capacity of base courses;
2) improvement of wearing course soil mortar by the use of binders;
3) action of sodium sulphate on soils;
4) effects of salts on bearing capacity of soils;
5) rammed earth construction;
6) seepage through dams.

The following special Indian testing equipment is mentioned:

a) The Puri Siltometer and the Optical Lever Siltometer for studying the size distribution of silts and sands;
b) Chaine hydrometer for mechanical analysis.

Concerning the compaction of soil, the conclusion is drawn that for the various soils of India the type of compaction to apply varies with the nature of the soil.

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SUB-SECTION XII b

INFORMATION ON EXISTING INSTITUTIONS AND PERSONS WORKING IN THE SPHERE OF SOIL MECHANICS AND THEIR SPHERE OF ACTION

XII b 1 STATEMENT OF EXISTING INSTITUTIONS HANDLING SOIL MECHANICS WORK IN SOUTH AFRICA

The application of the principles of Soil Mechanics has only really been seriously practiced in South Africa during the last decade and as yet the contributions by research to the world's knowledge have not been of great significance. The principle field of application has been to roadmaking techniques and examination of the following list of laboratories undertaking work in Soil Mechanics, bears out this statement:-

a) National Road Board, Pretoria: Research work on road construction, materials and procedures - 9 men working under the direction of Mr. J. Edwards, M.Sc., (Eng).
b) Cape Provincial Roads Department, Cape Town: Routine testing of road construction materials - 6 men working under the direction of Mr. C.V. Lewis, B.Sc., (Eng).
c) Orange Free State Provincial Roads Department, Bloemfontein: Routine Testing of road construction materials - 4 men working under the direction of Mr. G. Berman, B.Sc., (Eng).
d) Transvaal Provincial Roads Department, Pretoria: Routine testing of road construction materials - 5 men working under the direction of Mr. S. Kleyn, A.M.I.C.E.
e) Witwatersrand University, Johannesburg: Research work on road construction materials - 1 man working under the direction of Professor B. Knight, D.Sc.,
f) Council for Scientific and Industrial Research, Pretoria: Research work on foundations, retaining walls and other allied soil mechanics problems (not including roads) - 3 men working under the direction of Mr. J.E. Jennings, M.Sc., (Eng).

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XII b 2 THE BELGIAN GOVERNMENTAL INSTITUTE ON SOIL MECHANICS AT GENT

E. DE BEER (Belgium)

The Belgian Governmental Institute on Soil Mechanics has been created 10 years ago, and is a self supporting financially free Institute. Its purpose is to fulfil in place and in the laboratory all tests in connection with soil-mechanics, as well for privates as for public offices, and to formulate conclusions.

The layout of the Soil Mechanics laboratory of the Institute, located at the University of Ghent, is shown in fig. 1.

Finally there is a freezing box, having as internal dimensions 1,00 m x 0,80 m x 2,10 m, which can be divided into 2 parts, and which serves for freezing and thawing tests.

For the field the Institute disposes of 4 deep sounding apparatus, 2 handsounding apparatus, 2 medium sounding apparatus, 1 complete boring apparatus, 2 hand-boring apparatus, one transportable consolidation apparatus, and 4 apparatus for taking indisturbed samples.

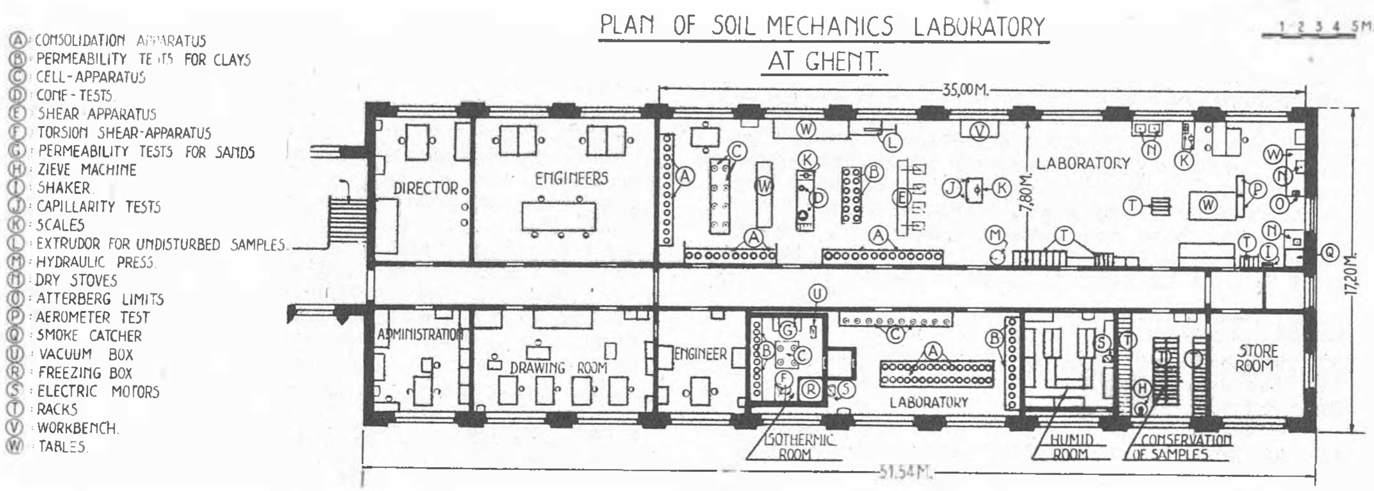

FIG. 1

The present staff of the laboratory consists, in addition to the writer, of L. Marivoet and H. Raedschelders, civil engineers, L. De Boeck, doctor in sciences, D. Suys and G. Smekens, laboratory technicians, O. De Boeck,- A. De Keyser, - J. Schepens, operators for field tests, J. Schoonbroodt and M. Stasino, technicians.

The number of the personal on January 1st 1946 was 23.

The equipment of the laboratory is the following:

61	consolidation apparatus	(type of Delft)
12	" "	(type Vander Haeghen)
18	cell apparatus	(type of Delft)
1	torsion shear apparatus.	
4	direct shear apparatus	(type of Delft)
2	cone test apparatus.	
1	compression test apparatus	(type of Delft)
1	compression test apparatus	(type Colling-Skempton)
1	Proctor apparatus.	
1	C.B.R. "	
1	microscop.	

Farther the laboratory is equiped for the usual soil tests such as limit determinations, graine size analyses, simple chemical analyses, volume weight and water content determination permeability tests.

For the conservation of the undisturbed samples the Institute disposes of an humid room, where the relative humidity is maintained at least at 95%. There is also an isothermic room, having 5,00 m x 4,20 m x 3,30 m, where the t° is maintained constant at 10° C. In this room all permeability tests and most of the cell-tests and consolidation tests are performed.

The most important practical studies performed till now are the following:

1) All soil problems connected with the new Motorroad Brussels-Ostand. 70 bridges, - 5 cuts, - 9 embankments.
2) The stability of the levees of the Albert-canal and of the other canals in Limburg.
3) The Canal around Ghent. 13 bridges, - a cut of 20,00 m depth.
4) The Canal Brussels - Charleroi. A cut of 43,00 m depth.
5) The Canal cut in Eigenbilzen (Albertcanal)
6) The foundation problem for 249 bridges.
7) The foundation problem for 152 buildings.
8) The soil problems for the construction of the airfield in Melsbroek.
9) The problems for the sewerage project of Ostend.
10) The soil problems for a new jetee at Zeebrugge.
11) 27 foundation problems of quaywalls.
12) Soft clay layers on a dam site at Eupen.
13) 8 problems of compaction of embankments.
14) 17 foundation problems of locks.
15) 2 investigations of "Urbanistry" areas.
16) Foundation- and Groundwaterlowering problems of the Albertine Library in Brussels.
17) Foundation problems at the "Gare du Nord et du Midi" in Brussels.
18) 2 studies for the stability of the slopes of stone-hills.
19) Soil problems for the canal Nimy-Blaton 4 bridges, - 4 cuts.
20) 2 stability problems of railway cuts.
21) 2 " " of railway embankments.
22) 2 pumping phenomena at the joints of rails.
23) 10 construction problems of main sewers in Brussels, Woluwe, Charleroi, Temsche. etc.

24) 2 groundwaterlowering problems in cemeteries.
25) 1 drainage problem.
26) 2 frost problems in roads.

For all these studies 2960 undisturbed samples and 37.680 disturbed samples were tested, and 1895 deep penetration tests performed.

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XII b 3

GEOTECHNICS IN SWEDEN x)

The Swedish National Committee of Geotechnics

In Sweden extensive geotechnical work is carried out by certain state and municipal institutions and also by some private firms and individuals. The main part of this activity is of a consulting nature and/or directly related to actual construction work. The research is not very extensive, and it is chiefly concentrated to a few state institutions.

A few data are given below about institutions, firms and individuals, who now are most active in Swedish geotechnics.

STATE INSTITUTIONS.

Statens Geotekniska Institut (The Royal Swedish Geotechnical Institute) Narvavägen 25, Stockholm.

The main functions of this institute are research work, consulting work, execution of special geotechnical processes and spreading of geotechnical knowledge. The consulting work and the executive work are requested and paid for by state and municipal authorities as well as by private firms and individuals. The activity concerns all kinds of buildings and civil engineering works and refers to the whole range of geotechnics, except questions relating to pavement and base courses of roads and airfields. The questions most frequently dealt with are ground-ruptures and earth-slides, settlements, foundation difficulties caused by ground-water, and erosion.

The institute has a comprehensive equipment for field and laboratory investigations.

The number of its personnel is now 57. Head of the institute is W. Kjellman. xa) The institute comprises a research department, head S. Odenstad and assistant G. Åström, a consulting department, head B. Jakobson and assistant G. Lindskog, and a mechanical department, head T. Kallstenius (grad.mech.eng.). Within the research department is a section for clay physics and chemistry headed by L. Silfverberg (M.Sc.).

Kungl. Järnvägsstyrelsens Geotekniska avdelning (The Geotechnical Section of the Swedish State Railway Board), Vasagatan 1, Stockholm.

The work of this department concerns embankments, bridges, houses and other structures of the state railways. Its main problems are the same as those of the Geotechnical Institute, but it also deals with testing ballast materials etc. The practical problems take most of the time, but some research is done in connection therewith.

The department has at its disposal a small laboratory and a rather comprehensive equipment for field investigations. It has a staff of 13. Head is B. Fellenius, assistant C. Wenner (Ph.D.. geologist).

Statens Väginstitut (The Royal Swedish Road Institute), Drottning Kristinas väg 25, Stockholm.

The activity of this institute includes certain geotechnical problems connected with base-pavement design of roads and airfields, mainly frost action, soil stabilization, exploration of gravel and binding soil materials. The institute has a comprehensive equipment for field and laboratory investigation of its special questions.

Head of the institute is N. von Matern. Of the staff about 20 are engaged in geotechnical work. Among them are G. Beskow, head of the geological department, F. Rengmark L.Sc. geologist), N. Odemark and N. Bruzelius.

Kungl. Vattenfallsstyrelsens Vattenbyggnadstekniska Byrå (The Civil Engineering Department of the State Power Board), Karduansmakaregatan 8, Stockholm.

When designing and building hydraulic structures, particularly large dams, this department sometimes encounters intricate geotechnical questions. Collaboration with the Geotechnical Institute is often established, especially regarding laboratory investigations. Officers to the department dealing with geotechnics are in the first place G. Westerberg, head of the department, P. Wittrock and J. Hagrup.

Sveriges Geologiska Undersökning (The Geological Survey of Sweden) Frescati, Stockholm 50.

This institution deals inter alia with geotechnical problems, particularly earth slides and ground water questions, from the geological research point of view. Research is also made on erosion, rock stability and core material for earth dams. Some of the officers, privately, carry out geotechnical consulting work. Head of the Survey is P. Geijer (Ph.D.). Most active in geotechnical questions are C. Caldenius (Ph.D.) and G. Ekström (Ph.D.).

Tekniska Högskolan (The Royal Institute of Technology) Valhallavägen 79, Stockholm.

Since 1947 this institute has a special section for geotechnics headed by B. Jakobsen. Certain geotechnical problems are dealt with also in other sections, particularly by B.

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x) "Geotechnics" is a literal translation of the Swedish equivalent to "Soil Mechanics and Foundation Engineering". It is used instead of this cumbersome expression throughout the present paper.

xa) Unless otherwise stated all persons mentioned in this paper are graduate civil engineers.

Hellström. The activity is mainly teaching, but some research work is carried out.

Chalmers Tekniska Högskola (Chalmers Institute of Technology), Storgatan 43, Göteborg.
No special section for geotechnics exists, but geotechnical problems are treated in several sections, particularly by S. Hultin, Hj. Granholm and T. Hultin. The activity is mainly teaching, but some research work is also carried out.

MUNICIPAL INSTITUTIONS.

Stockholms Gatukontors Geotekniska Avdelning (The Geotechnical Section of the Public Works Office, Stockholm), Stora Nygatan 2 B, Stockholm.
Geotechnical questions concerning streets, tunnels, viaducts and houses in Stockholm are treated. The section has at its disposal a small laboratory and some field equipment. The staff is about 10. Head is A. Hellgren.

Stockholms Hamnstyrelses Byggnadsavdelning (The Stockholm Harbour Board, Building Department), Katarinavägen 13 A, Stockholm.
Geotechnical questions concerning quays, locks, bridges etc. in Stockholm are treated. Some research work is also performed. The department has a small laboratory and a field equipment but no personnel specialized in geotechnics. Most active in geotechnical questions are H. Jansson, head of the department, A. Wickert and A. Rinkert.

Göteborgs Hamningenjörskontor (The Engineering Office of the Harbour Board of Gothenburg), Norra Hamngaten 10, Göteborg.
Geotechnical questions concerning quays, bridges, houses etc. in Gothenburg are treated. Some research work is also performed. The office has an equipment for field and laboratory investigations.
Head of the office is T. Hultin. Of the staff 6 persons are engaged in geotechnical work. Among them is J. Marve.

PRIVATE FIRMS.

Geotekniska Byrån, Drottninggatan 27, Stockholm.
This firm of engineers carries out geotechnical consulting work only. The problems are chiefly the same as those dealt with by the Geotechnical Institute. The firm has a laboratory and some field equipment. The staff amounts to 12. Head is G. Bjurström (Ph.D.)

Ekmans konstruktionsbyrå, Klostergatan 7-9, Örebro.
The main activity of this firm consits in geotechnical consulting work. It has a laboratory and some field equipment. The staff is about 5. Head is C.G. Ekman.

Vattenbyggnadsbyrån, Humlegårdsgaten 29, Stockholm.
This is a large firm of consulting engineers designing, especially, all kinds of hydraulic structures. The very difficult geotechnical problems often attached to such buildings are solved by the firm's own engineers, often in collaboration with the Geotechnical Institute, particularly concerning more elaborate laboratory investigations. Sometimes extensive research work is performed by the firm, which has a small laboratory and some field equipment. The members of the firm dealing with geotechnics are in the first place F. Samsioe (D.Techn.), P.W. Werner, E. Ljung, G.Alm and E. Reinius.

Skånska Cementgjuteriet AB, Norrlandsgatan 7-9, Stockholm.
This ia a large firm of building-contractors which has its own geotechnical specialist, N. Engström, with 2 to 4 assistants. The work chiefly refers to various kinds of practical problems but some research work is also carried out. The firm has a small laboratory and some field equipment.

INDIVIDUALS.

J. Olsson, Tre Liljor 1, Stockholm.
Mr. Olsson, one of the pioneers of Geotechnics and previously head of the Geotechnical Department of the State Railways, is now working as a consulting engineer within the range of geotechnics.

R. Lidên (Ph.D.), Stavgårdsgatan 44, Stockholm.
Mr. Lidên is a geologist, previously employed by the Geotechnical Department of the State Railways. Mr. Lidên is now working as a consultant in geotechnics.

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XII b 4 — T. G. MASARYK INSTITUTE

Czecho Slovakia

Name and address:

Soil Mechanics and Foundation Laboratory in the T.G. Masaryk National Hydrological Institute-Prague XIX, Podbaba.

The main purpose of the laboratory is the determination of physical properties of soils with a view to their suitability as building material (building of dams, road and rail embankments) and for foundations. It also serves for teaching purposes of the Technical University of Prague.

Name of staff personnel and specialists:

Ing. Dr. Alois Myslivec, Professor of the Technical University of Prague
Ing. Josef Francek, Head of the Laboratory
Ing. Josef Havlíček, Foundation specialist
Richard Pochman, assistent.

The total number of employees is 13 persons apart from research students.

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XII b 5

THE DANISH INSTITUTE OF SOIL MECHANICS

A. F. MOGENSEN

Act. Professor, The Technical University, Copenhagen, Denmark.

In this report a description will be given of the Danish Institute of Soil Mechanics.

a) Name and address of the institute:
GEOTEKNISK INSTITUT,
Øster Voldgade 10,
Copenhagen,
Denmark.

b) Purpose:
Investigations in field and laboratory for application to practical purposes.
Scientific research.

c) Names of staff:
A.F. Mogensen, act. Professor, in charge of the institute,
A.V. Knudsen, Civil Engineer,
Ellen Louise Mertz, Geologist (The Danish Geological Survey),
Sv. Østrup, Civil Engineer (The Technical University of Denmark),
J. Jakobsen, Engineer,
moreover Professor A.E. Bretting is acting as special adviser to the institute.

d) Number of assistants:
In addition to the staff mentioned above a number of assistants are at present employed by the institute, viz.:
1 laboratory assistant,
2 draughtsmen,
1 clerk (in common with the laboratory of the technical university.).

In Denmark geotechnical research was started in 1923 by the DENMARKS GEOLOGISKE UNDERSØGELSE (THE DANISH GEOLOGICAL SURVEY), Department for Investigation of clay. This department is now carrying on research on physical and chemical properties of soils, and is working particularly with classification of soils. Prior to the establishment of the GEOTEKNISK INSTITUT (INSTITUTE OF SOIL MECHANICS) the said department acted in the capacity of adviser in connection with a number of foundation works.

Since 1930 DE DANSKE STATSBANER (THE DANISH STATE RAILWAYS) have been making geotechnical investigations in their own laboratory.

At the DANMARKS TEKNISKE HØJSKOLE (THE TECHNICAL UNIVERSITY OF DENMARK), Copenhagen a geotechnical laboratory was established in 1937 and provided with a fully op-to-date equipment of testing devices etc., which laboratory constitutes a branch of LABORATORIUM FOR HAVNEBYGNING OG FUNDERING (LABORATORY FOR MARITIME AND FOUNDATION WORKS). This new laboratory was intended to carry on geotechnical research, particularly with a view to engineering purposes, and to be used for educational purposes as well. Before long the laboratory was requested to make investigations of soils on behalf of various institutions and private engineering and contracting firms, and to undertake consultative tasks. With a view to accomplishing these tasks in the best possible way the laboratory entered into collaboration with DANMARKS GEOLOGISKE UNDERSØGELSE (THE DANISH GEOLOGICAL SURVEY), which institution thereafter supplemented the works of the laboratory by statements on geological circumstances relating to the sites investigated.

Gradually, as demands for geotechnical investigations were increasingly made on the part of people employed in practice, it was realized that, in the way used so far, the collaboration of the two institutions would be rather inexpedient and troublesome. Therefore Professor G. SCHØNWELLER, then in charge of the laboratory, approached AKADEMIET FOR DE TEKNISKE VIDENSKABER (THE ACADEMY OF TECHNICAL SCIENCE), suggesting a coordination of geotechnical research into a GEOTEKNISK INSTITUT (INSTITUTE OF SOIL MECHANICS).
This institute should take the charge of geotechnical research activities, and should make geotechnical investigations for institutions and private firms.

On the 18th May, 1943 the council of the academy agreed to establish the said institute on the basis of the existing collaboration between the laboratory of the technical university and the geological survey.

The institute constitutes an independent institution within the academy, and its activities are controlled by a board appointed by the council of the academy. The aim of the institute is to promote geotechnical science in Denmark, and particularly its application to practice. The institute undertakes geotechnical investigations, and gives advice relating to application of the results to practice.

The articles of the institute stipulate that the leader of the LABORATORY FOR MARITIME AND FOUNDATION WORKS of THE TECHNICAL UNIVERSITY OF DENMARK is also in charge of the INSTITUTE OF SOIL MECHANICS and that, against a certain consideration, the institute is allowed to use the premises and equipment of the aforementioned laboratory. On the other hand, in regard to administration and accounts it is fully independent of same. Thus the purpose of the laboratory of the technical university are merely relating to research and education.

THE DANISH GEOLOGICAL SURVEY and THE TECHNICAL UNIVERSITY OF DENMARK each appoint a member of the staff of the institute, a geologist and an engineer respectively, which members are to be at the disposal of the institute for a certain time every day. Other staff etc. are to be employed by the institute directly.

Fig. 1 represents the premises used for laboratory and offices. In addition to in-

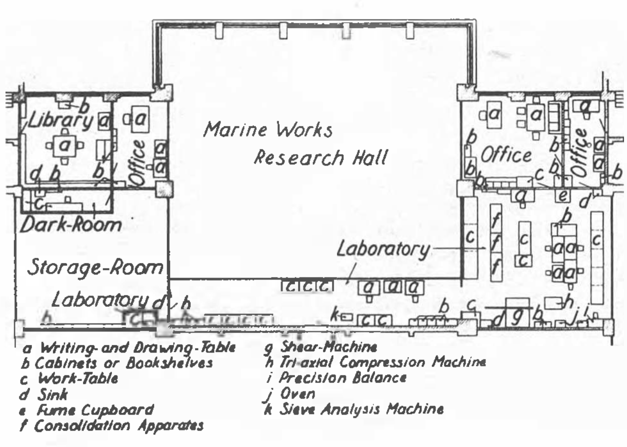

FIG. 1

struments and devices indicated in the plan the institute possesses the types of geotechnical instruments generally used. The institute is allowed to make use of workshops etc. belonging to the laboratory of the technical university.

The institute undertakes the performance of borings with extraction of undisturbed samples. In case of more extensive borings the institute collaborates with a contractor.

Up to this date (January 1948) the institute has made investigations for practical purposes in about 200 cases. Short reports are published in MEDDELELSER FRA AKADEMIET FOR DE TEKNISKE VIDENSKABER (PROCEEDINGS OF THE ACADEMY OF TECHNICAL SCIENCE).

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XII b 6 THE SOIL MECHANICS DIVISION OF THE BUILDING RESEARCH STATION, GREAT BRITAIN

L. F. COOLING, M. Sc.

The Building Research Station, which is situated at Garston, near Watford, Hertfordshire, England, is one of the Government Research Stations of the Department of Scientific and Industrial Research. As such it is primarily a research organization in close touch with the industry but it is frequently called upon to serve in an advisory capacity in respect of problems brought forward by other Government Departments and Ministries.

The Soil Mechanics Laboratory was formed in September 1933 with two main objects in view. The first was to undertake a programme of research on soils in relation to road problems on behalf on the then newly formed Road Research Board and the second was to continue the research on earth pressures and foundation problems which had been commenced by Prof. C.F. Jenkin x). As a result of the rapid and considerable growth of interest in the subject during the ensuing years it was decided in 1937 to form a separate Soils Laboratory at the Road Laboratory to take over the study of problems more particularly concerned with road construction. Since 1937 the Building Research Station Soils Laboratory has concentrated on problems relating to building and heavier civil engineering works including the following:-

(1) Foundations (including piling) and excavations.
(2) Earth pressure on retaining structures and tunnels including the stability of retaining walls, docks, quay walls etc.
(3) Stability of natural slopes, cuttings and embankments.
(4) Earth dams.
(5) Research into soil properties, soil tests and methods of site investigation.
(6) Field measurements to study the performance of structures including measurements of earth pressure, deformation and settlement, water pressures and water flow.

Since its inception the Laboratory has played a prominent part in forwarding the application and development of Soil Mechanics in Great Britain. This it has done by means of papers in the technical press, by the training of engineers from various organizations (such as universities, railway companies, contracting engineers, etc.), by lectures and numerous contacts in the course of investigations of practical porblems. A list of the papers issued from the laboratory between 1940 and 1947 is given at the end of the paper.

During the war, the calls made upon the Laboratory by other Government Departments were such that the work was almost entirely diverted to the investigation of specific practical problems. These problems were of two kinds; the first was concerned with failures in important civil engineering works where investigations were required to establish the cause of failure and to decide on appropriate remedial measures; the second was concerned with site investigations prior to the construction of new works to obtain information for design purposes. The range of problems, covered in some 60 investigations, was very wide and included such problems as the study of failures in earth dams, retaining walls and quay walls, protective earth mounds, factories and industrial buildings and in cold storage buildings, site investigations were made for the design of graving docks, flood protection and drainage channels, grain silos, factories and other large buildings. Papers describing some of the more important of these problems are included in those submitted to the Conference.

The laboratory is equipped with all the apparatus necessary for carrying out soil investigations. It has also developed a number of type designs of apparatus which are being widely used in this country for the investigation of the mechanical properties of soils. These include the portable compression machine (Ref. 1 in the list of papers given below), constant rate of strain shear box (Ref. 7), consolidation apparatus (Ref. 2) triaxial machine with constant rate of strain, permeability apparatus and a sampling tube for taking "undisturbed" soil samples (Ref. 5).

The Soil Mechanics Division is now making an effort to resume its long term programme of fundamental research on the six groups of problems outlined above.

The personnel staffing the laboratory at present is as follows:-

L.F. Cooling, M.Sc., (Officer in Charge).
W.H. Ward, B.Sc., A.C.G.I., A.M.I.C.E.
G.G. Meyerhof, M.Sc.(Eng.), A.M.I.C.E.
L. Casagrande, Dr. Ing.

---

x) Jenkin, C.F. "The Pressure on Retaining Walls", Proc. Inst. C.E., Vol. 234, 1931, p. 103.

A. Penman, B.Sc. (Eng.).
A.D. Smith, B.Sc. (Eng.)
T.K. Chaplin, B.A. (Eng.).
A.G. Loudon, B.Sc (Physics).
Mrs. M.E. Butler, B.Sc, (Geology).
S.G. Samuels.

Apart from the general work of the Division the following special lines of investigation are being pursued.

Mr. Ward, assisted by Mr. Penman and Mr. Smith, is making a special study of stability problems, including laboratory investigations of the shearing characteristics of soils, field and laboratory studies of porewater pressures, and field measurements of earth pressures.

Mr. Meyerhof, assisted by Mr. Chaplin, is making a special study of bearing capacity and foundation problems including model tests in the laboratory to investigate shallow and deep foundations and field measurements of the settlement of structures.

Dr. Casagrande, assisted by Mr. Loudon and Mr. Samuels, is making a special study of electro-osmosis in soils, electro-chemical hardening and the effects of base exchange on the mechanical properties of clay-type soils.

A general account of the work of the laboratory is published in the Annual Reports of the Building Research Board. Detailed descriptions of the results of investigations are published from time to time either in the technical press or in publications of H.M. Stationery Office.

LIST OF PAPERS FROM BUILDING RESEARCH STATION SOIL MECHANICS LABORATORY 1940-'47

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2) Cooling, L.F. and A.W. Skempton. Some experiments on the consolidation of clay. Inst. Civ. Eng. J., 1941, 16, (7), 381-98.
3) Golder, H.Q. The ultimate bearing pressure of rectangular footings. Inst. Civ. Eng. J., 1941, 17, (2), 161-74. Correspondence. Supplement to Journal No. 8, pp. 458-63.
4) Cooling, L.F. and A.W. Skempton. A laboratory study of London clay. Inst. Civ. Eng. J., 1942, 17, (3), 251-76; correspondence. Supplement to Journal, No. 8, 497-501.
5) Cooling, L.F. Soil mechanics and site exploration. Inst. Civ. Eng. J., 1942, 18, (5), 37-61; discussion 18, (6), 155-80.
6) Skempton, A.W. An investigation of the bearing capacity of a soft clay soils. Inst. Civ. Eng. J., 1942, 18, (7), 307-21. Correspondence. Supplement to Journal, No. 8, 567-76.
7) Golder, H.Q. An apparatus for measuring the shear strength of soils. Engineering, 1942, 153, 501-2.
8) Cooling, L.F. and H.Q. Golder. The analysis of the failure of an earth dam during construction. Inst. Civ. Eng. J., 1942, 19, (1), 38-55
9) Skempton, A.W. Some principles of foundation behaviour. R.I.B.A.J., 1942, 50, (1), 3-6.
10) Skempton, A.W. The compressibility of argillaceous sediments. Geol. Soc. Q.J., 1944, 100, 119-35.
11) Cooling, L.F. and W.H. Ward. Damage to cold stores due to frost heaving. Institution of Refrigeration, Proc., 1944-5, 41, 37-47; discussion, 48-58.
12) Skempton, A.W. A slip in the West Bank of the Eau Brink cut. Inst. Civ. Eng. J., 1945, 24, (7), 267-87.
13) Ward, W.H. The stability of natural slopes. Geographical J., 1945 105, (5/6), 170-97.
14) Glossop, R. and A.W. Skempton. Particle-size in silts and sands. Inst. Civ. Eng. J., 1945, 25, (2), 81-105.
15) Cooling, L.F. Some foundation troubles with small houses. J. Inst. Sanitary Engrs., 1946, 45 327-347.
16) Cooling, L.F. Skempton, A.W., Glossop, R. and A.H.D. Markwick. The principles and application of soil mechanics. A series of four lectures given to the Institution of Civil Engineers in June, 1945. Published by the Institution of Civil Engineers, Great George St., Westminster, S.W.1., 1946.
17) Ward, W.H. House foundations. Journal of the Royal Institute of British Architects, February 1947.
18) Ward, W.H. The effects of fast growing trees and shrubs on shallow foundations. Journal of the Institute of Landscape Architects, April 1947.
19) Casagrande, L. The application of electro-osmosis to practical problems in foundation and earthworks. Building Research Technical Paper No. 30. H.M. Stationery Office, London, 1947.

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XII b 7

SOIL MECHANICS LIMITED: ORGANISATION AND EQUIPMENT

R. GLOSSOP. B.Sc., A.M.I.C.E.

This laboratory originally installed in 1939 on the site of a large earth dam by the main contractors John Mowlem and Company Limited, proved so useful in solving the many problems which arise in a large contracting firm, that, having fulfilled its original purpose, it was transferred to larger premises at 123, Victoria Street, from which a specialist contracting firm "Soil Mechanics Limited" now operates.

Here the laboratory not only furnishes design data from site investigations carried out for Consulting Engineers and Public Bodies, but also forms the nucleus of a firm specialising in difficult excavation works, underpinning and foundations, and employing a wide range of devices and processes such as bored piles, chemical consolidation, ground water lowering, soil stabilisation and compressed air work. In this second capacity the laboratory has proved invaluable in providing accurate data from which such operations can be planned with the certainty of success.

ORGANISATION AND ACTIVITIES.

The activities of this firm can be divided into four groups.

1) Site Investigations
This group includes, Topographical and geological surveys, resistivity surveys, boring, sampling and laboratory testing of soils, percussion boring, diamond drilling, deep sounding tests, loading tests, pile loading tests, the analysis of problems.

2) Geotechnical Processes.
Injection processes using silicates (Joosten and Guttman processes), cement grout and bitumen emulsions. Ground water lowering by deep wells, shallow wells and well points. Soil stabilization.

3) General Works.
Contracts carried out include excavation in water bearing ground using ground water lowering, compressed air, steel sheet piling and bored sheet piling. Underpinning by bored piles and otherwise.

4) Research.
Fundamental research is not undertaken, but many opportunities arise for observations in the field, and work has been done on the design of apparatus and the development of laboratory techniques. A bibliography is given of papers published by the laboratory staff.

EQUIPMENT.

1) Boring.
Since boring in soft ground for foundations need rarely exceed 100 feet in depth the old fashioned hand boring methods have proved the most satisfactory, indeed mechanical methods may be positively dangerous, since with them the possibility of failure to sample at every change of ground is much greater than with the slower and more laborious method. The greatest difficulty in establishing a sound technique has been to teach foremen trained in well boring methods that careful sampling is all that matters in site investigations and must never be sacrificed for a high rate of progress. Light diamond core drills are used to prove bed rock and their use has frequently been justified when apparently solid bed rock has proved to be a large boulder. Such experiences have shown that in exploring dam site foundations through moraine core boring should be taken 20 feet into solid rock. In boring through slag heaps and bouldery moraine heavy percussion drills of the Ruston-Bucyrus Type are used.

2) Undisturbed Samplers.
The device used for taking undisturbed samples of clay is illustrated in Photographs Nos. 1, 2, 3, & 4. It was developed by the laboratory staff and has now been adopted by a number of other organisations in Great Britain. It is simple, robust and has proved most satisfactory. A sampler for non-cohesive soils devised by Mr. D.W. Bishop and the writer is based on displacement of water from the sand by compressed air. Laboratory tests have been successful and a prototype is being built.

3) In-situ Tests.
Pile loading tests to check dynamic pile formulae are in progress. The laboratory is equipped with a deep sounding device supplied by the University of Delft. Work is in progress with the Resistivity method for the location of bed rock.

4) Laboratory Tests.
The laboratory differs from those intended for teaching and research in that the number of samples tested is very great. To prevent confusion, methods of testing have been standardised as far as possible and much use is made of standard forms.

a) Sample Storage and Preparation Room.
Undisturbed samples in their tubes and disturbed samples in screw topped bottles are stored in racks (Photograph No. 5), and are first examined by the geologist who checks the boring foreman's observations and prepares a preliminary borehole log which is sent to the drawing office for tracing. Samples are also examined by the engineer in charge of the investigation who writes out a

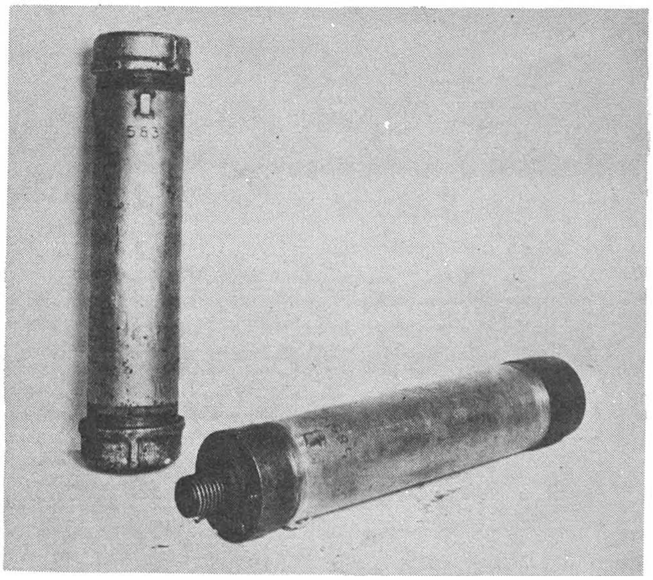

FIG. 1

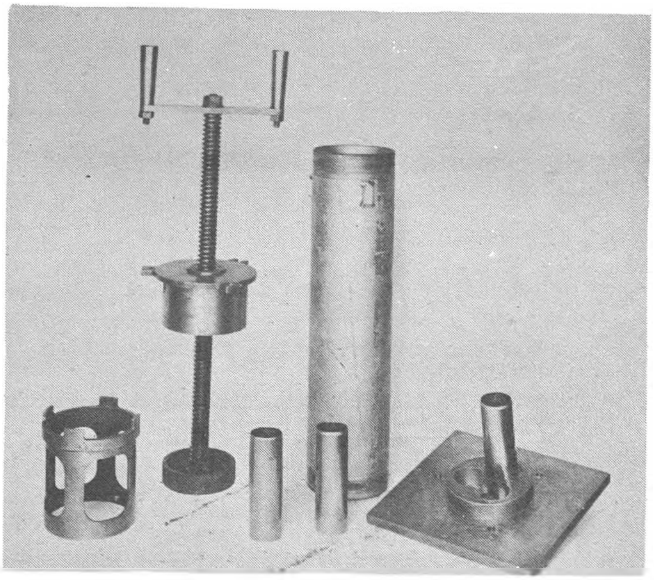

FIG. 2

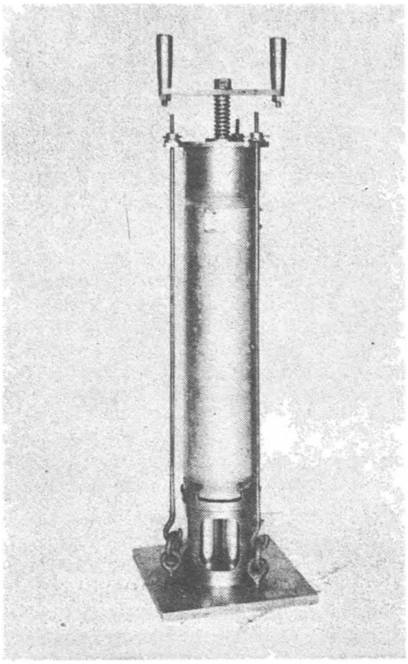

FIG. 3

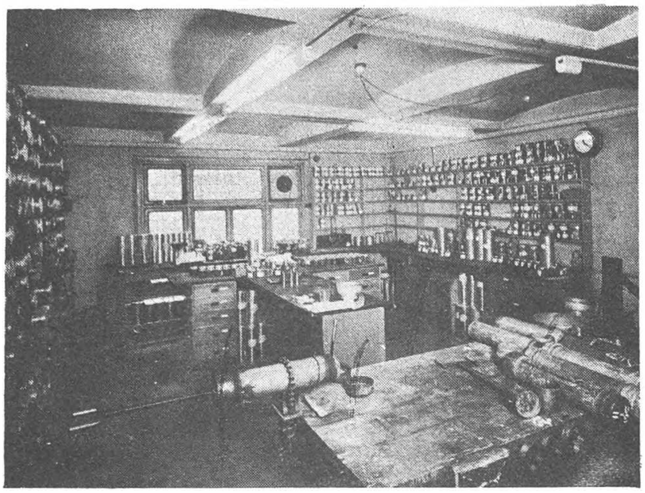

FIG. 5

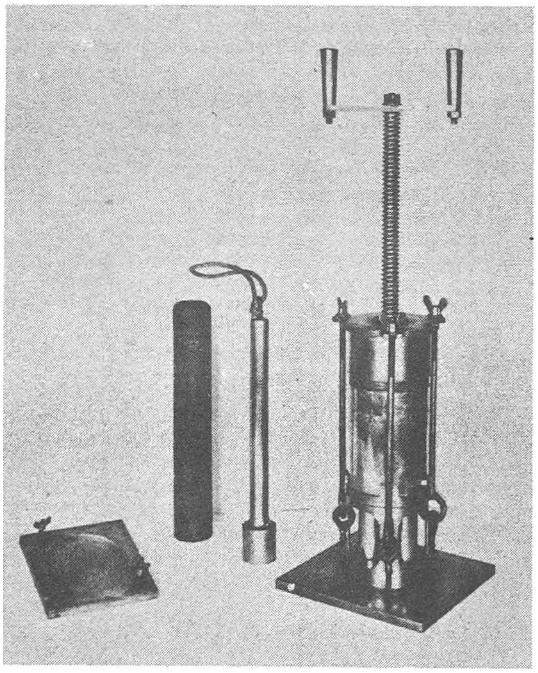

FIG. 4

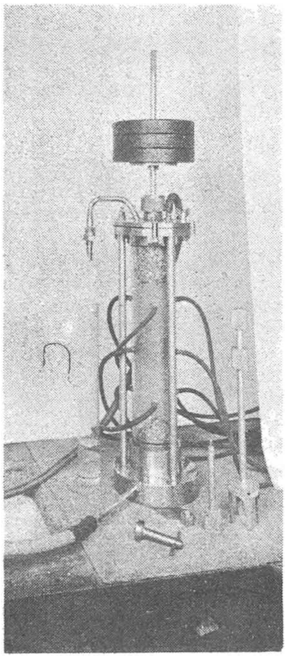

FIG. 6

testing programme for the laboratory superintendent.

b) Index Properties, Sizing Analysis, Permeability.

The moisture content of all samples is measured as a matter of routine, the liquid and plastic limits on selected samples only. Sizing analysis of + 200 mesh material is made by dry sieving and on - 200 mesh material by the hydrometer method, such tests are chiefly of value in cases where the use of water lowering or injection processes are contemplated in the design of inverted filters.

A permeameter of the constant head type is used (Photograph No. 6).

c) Shear Strength Measurements.

The shear strength of stiff fissured clays is measured in the triaxial apparatus (Photograph No. 7) which is of the constant rate of strain type. The loading frame is also used for unconfined compression tests, but for this test a portable spring loaded device is also used (Photograph No.8).

Equilibrium shear tests are made in an electrically operated constant rate of strain shear box (Photograph No. 9).

d) Consolidation Tests.

A consolidation press with four cells has recently been designed and built. The cells are of the ring type suggested by Professor A. Casagrande and the loading system is compact and easy to oper-

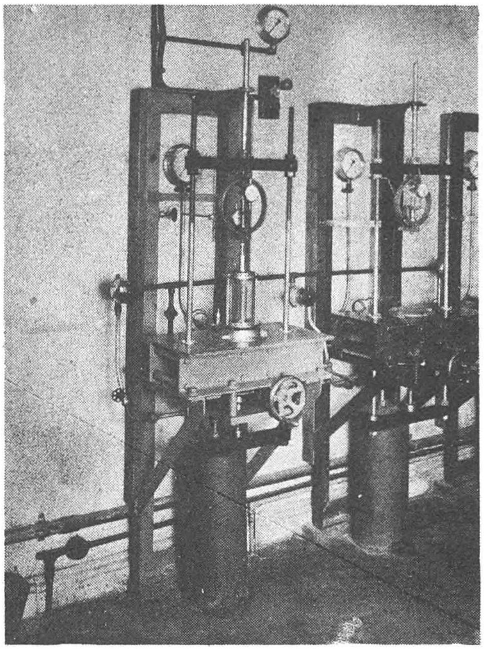

FIG. 7

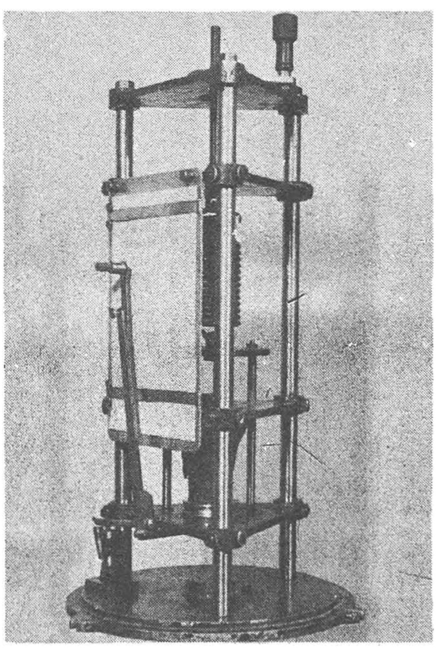

FIG. 8

ate. (Photographs Nos. 10 & 11).

e) Compaction.
Compaction tests are made in the standard Proctor apparatus and in the type described in a paper to this conference by Mr. Little.

f) Geological Laboratory.
This laboratory is equipped with microscope, slide cutting apparatus, refractive index liquids, etc.

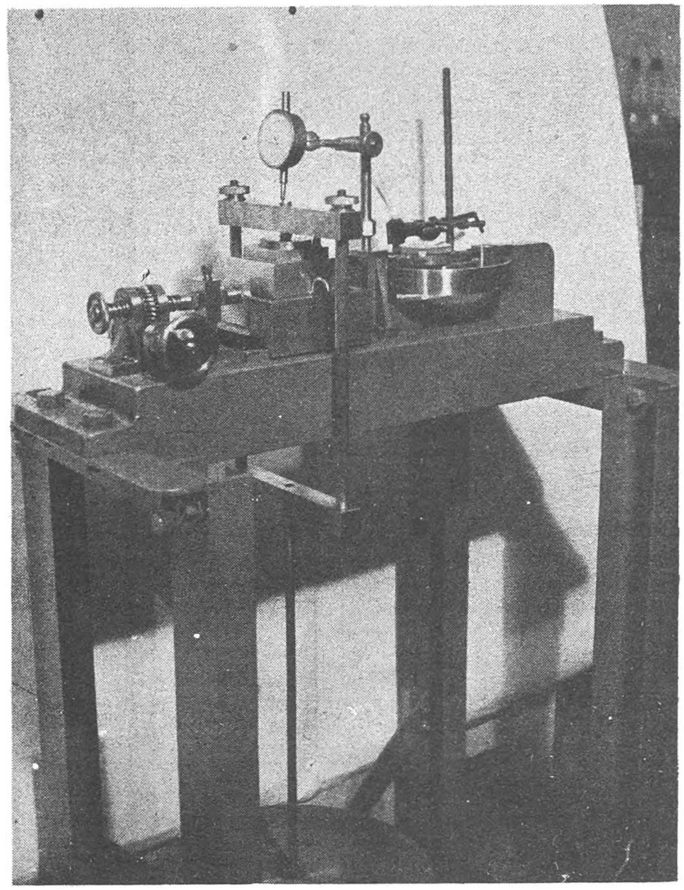

FIG. 9

TECHNICAL STAFF

Works directors
H.J.B. Harding, B.Sc., M.I.C.E.
R. Glossop, B.Sc., A.M.I.C.E.
H.Q. Golder, M.Eng., A.M.I.C.E.

Senior Engineers
V.H. Collingridge. A.C.G.I., A.M.I.C.E.
I. Greeves, A.M.I.C.E.

Laboratory superintendent
A.L. Little, B.Sc., A.M.I.C.E.

Engineers
A.R. Harris, A.M.I.C.E.
S.H. Clisby, B.Sc., A.R.S.M.
D.A. Cumming, B.A.
F.A. Sharman, B.Sc., A.M.I.C.E.
L.F. Offer, B.Sc., A.M.I.C.E.
B. Crowther, B.Sc.
I.K. Nixon, A.M.I.C.E.

Geologist
K.R. Early, B.Sc., A.R.S.M.

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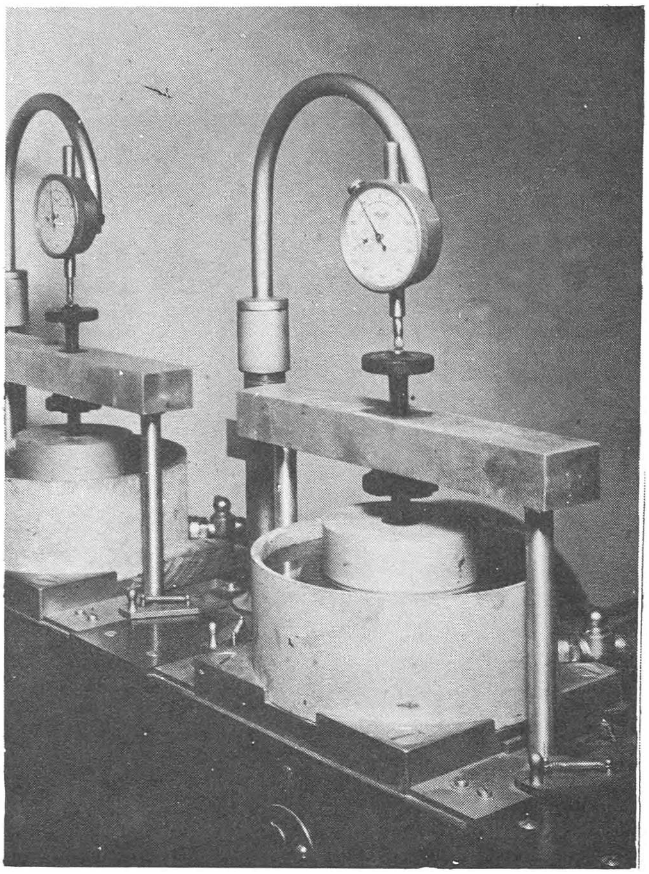

FIG. 10

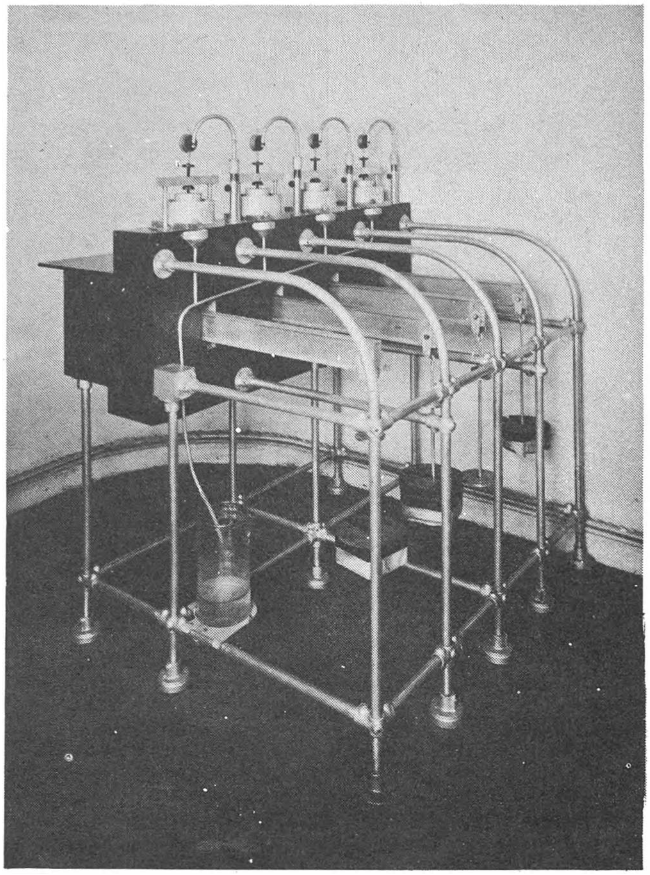

FIG. 11

(Glasgow Association) March, 1945.
4) "An Improved Clay Sampler." A.R.C. Longsdon. The Engineer. August, 1945.
5) "Soil Bearing Tests and Foundation Design." H.Q. Golder. The Liverpool Engineering Society. Oct., 1945.
6) "Modern Ideas on Retaining Walls." A.L. Little. Junior Section Institution of Structural Engineers. Nov., 1945.
7) "Particle Size in Sands and Silts." R. Glossop & A.W. Skempton. Journal Institution of Civil Engineers. Dec., 1945.
8) "The Principles and Practise of Ground Water Lowering." H.J.B. Harding. Institution of Civil Engineers (Glasgow Association). February, 1946.
9) "The Principles and Application of Soil Mechanics." A Record of Four Lectures delivered at The Institution. 3rd Lecture by R. Glossop. Institution of Civil Engineers. 1946.
10) "Sub Soil Drainage with Particular Reference to Road Engineering." R. Glossop. Institution of Civil Engineers (Road Divisin). Nov., 1946.
11) "Specialist Methods in Civil Engineering Construction." R. Glossop. Liverpool Engineering Society. November, 1946.
12) "The Choice of Expedients in Civil Engineering Construction." H.J.B. Harding. Institution of Civil Engineering (Works Division). December, 1946.
13) "A New Form of Bored Pile." R. Glossop & I.S. Greeves. Concrete and Constructional Engineering. December, 1946.
14) "Relationship of Runway Thickness and Undercarriage Design to the Properties of the Sub-grade Soil." H.Q. Golder. Institution of Civil Engineers (Airport Paper No. 4). December , 1946.
15) "Underpinning a Church at Ealing." H.J.B. Harding & V.H. Collingridge. Concrete and Constructional Engineering. May, 1947.
16) "Le Développement de la Géotechnique en Angleterre". H.Q. Golder. "Verre et Silicates Industriels". Bruxelles, 1947.

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XII b 8

THE SOIL MECHANICS SECTION OF THE ROAD RESEARCH LABORATORY (GREAT BRITAIN)

D.J. MACLEAN

SUMMARY

This papers describes the organisation of the Soil Mechanics Section of the Road Research Laboratory, a British Government Laboratory forming part of the Department of Scientific and Industrial Research.

The various sub-sections are described briefly with a few notes on the work done and on the programme of work. Photographs of some of the laboratories are included and a list is given of the papers published to date by members of the Section.

Introduction

This paper gives information concerning the Soil Mechanics Section of the Road Research Laboratory.

Address

The address of the Road Research Laboratory is:-

Road Research Laboratory,
Department of Scientific and Industrial Research,
Harmondsworth,
West Drayton,
Middlesex,
England.

ROAD RESEARCH LABORATORY

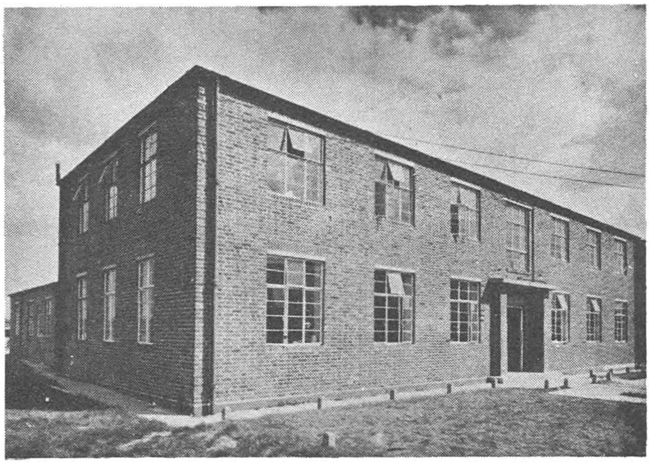
The Road Research Laboratory is one of the constituent laboratories of the Department of Scientific and Industrial Research a Government Department which undertakes and fosters scientific research on may subjects. The Laboratory, which is directed by Dr. W.H. Glanville, C.B.E., M.I.C.E., carries out research on all matters concerned with the road and its usage. There are two main divisions of the Road Research Laboratory - the Materials and Construction Division and the Road Safety Division. Soil Mechanics research is undertaken by a Section of the Materials and Construction Division.

History of Soil Mechanics Section

The Soil Mechanics Section was formed in April, 1937 under the leadership of the late Mr. A.H.D. Markwick, M.Sc, M.I.C.E. In the period prior to the beginning of the war up to September, 1939, the Section was engaged in studying existing methods of measuring the properties of soil and undertook several soil surveys for the Ministry of Transport in connexion with new road construction. Research on soil mechanics was largely suspended at the beginning of the war, but it subsequently became apparent that there were many war problems in which soil mechanics could play a valuable part. In consequence, the Soil Mechanics Section was rapidly developed to meet this requirement. The main expansion of the Section took place in 1943, and it is since that date that most of the research of the Section has been done. In March, 1946, the Section suffered a severe blow by the premature death of Mr. Markwick, who had been one of the main British contributors to Soil Mechanics. The Section has since been under the charge of the writer.

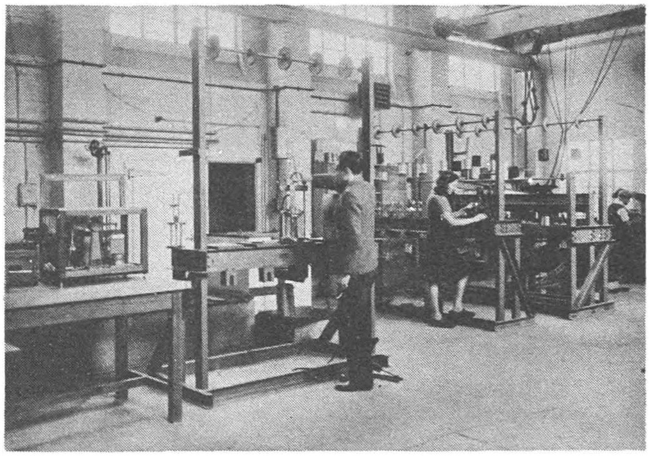
SOIL MECHANICS LABORATORY

The Soil Mechanics Section is housed in the building shown in fig. 1. Some of the laboratories contained in this building are shown in fig. 2 to 5.



The Soil Mechanics Laboratory.

FIG. 1



The Main Laboratory.

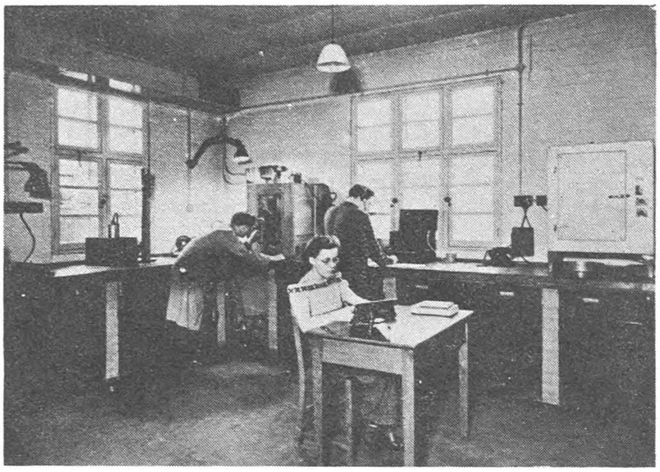
FIG. 2

Organisation and Work of the Section

The number of personnel employed in the Section is 30, and the research is divided into seven sub-sections. These are as follows:

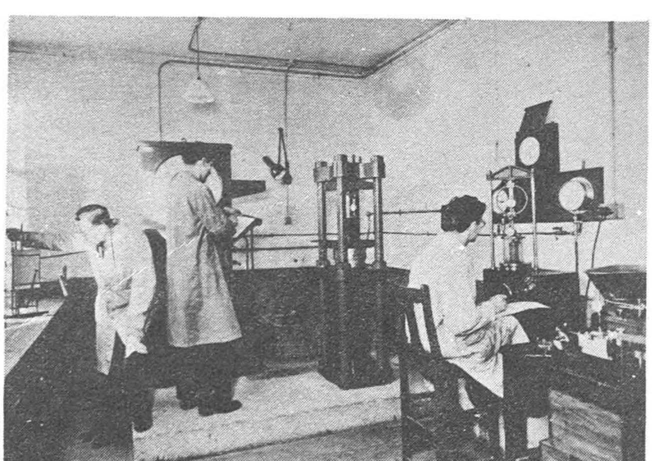
1) Soil Physics - This sub-section is led by Mr. D. Croney, B.Sc., and is concerned with research on soil moisture problems and frost damage in relation to road subgrades.

The principal study of this sub-section is the cause of changes of moisture content



The Soil Physics Laboratory.
FIG. 3

The Soil Chemistry Laboratory.
FIG. 4



Laboratory for Mechanical Tests on Soil.
FIG. 5

in road subgrades due to the movement of moisture in the soil. Laboratory investigations have been made of the relationship between the negative pressure of moisture in unsaturated soil with respect to a free water surface and soil type and moisture content. The results of these investigations are being used to derive the equilibrium moisture gradient above a water table. On one site the theoretical gradient agreed closely with the actual moisture content. The relationship between negative pressure in unsaturated soil and the vapour pressure of soil has been derived mathematically from fundamental thermodynamical principles, and the effect of temperature on these properties has been determined.

Studies have also been made of moisture transfer by water vapour movements in soil, particularly when a temperature gradient exists in the soil. It has been found that soil is highly permeable to vapour movements which assume particular importance during drought conditions, when the soil becomes sufficiently dry to permit such movements on a large scale.

The future work of this sub-section includes the completion of the present laboratory studies and long-term studies of the movement of moisture under experimental roads in which the subgrades will be prepared under carefully controlled conditions of density and moisture content. In this connexion an improved type of electrical instrument for measuring moisture content is in course of development.

2) Soil Chemistry - This sub-section is led by Mr. K.E. Clare, B.Sc., and is concerned with the development of methods of determining the chemical constituents of soil, the development of methods of waterproofing soils and the study of soils occurring in British colonies. Preliminary studies have been made of the relationship between clay mineral type and soil properties and it is hoped to expand this side of the work.

The development of chemical tests is being undertaken with particular reference to soil stabilization. For example, if the organic or sulphate content of a soil is excessive, the stabilization of the soil with cement is impracticable. Similarly, the p^H value of a soil can affect its waterproofing with resinous materials. It is therefore necessary to be able to determine those chemical properties of soils. A study has been made of tests for determining organic content and tests are in progress on the sulphate test in which the main problem appears to be that of leaching the sulphate from the soil.

Other chemical tests are being developed for estimating the stabiliser content in processed soils. A satisfactory test for determining the cement content of soil-cement has already been developed.

A large part of the work of the sub-section has been devoted to studies of the waterproofing of soils by adding resinous and other materials. A capillary water absorption test has been devised for estimating the efficacy of such materials. Using this test, a variety of resins, including some from tropical areas, have been compared, and it has been shown that resins are effective only in acidic soils. In a search for materials suitable for waterproofing alkaline soils, it has been found that the sodium salts of certain fatty acids are suitable, but further research on these chemicals is required. Some work of a fundamental nature has been under taken to determine the mechanism of the waterproofing action of resinous materials, and it appears that resins spread on the air-water interface in soil thus forming films which resist water movement. On the basis of this hypothesis a tropical resin was chemically modified to form a more stable film and therefore give a better waterproofing effect. These studies are being continued by Langmuir through investigations and other fundamental work.

A limited number of full-scale trials have been made with waterproofing chemicals, and it is hoped to make extensive trials in the near future to relate the results of the capillary water absorption test with field behaviour and check the efficacy of these chemicals in practice. The bacterial attack on resinous materials in soils has been studied for the Road Research Laboratory at the Rothamsted Experimental Station, Harpendon by Mr. P.C.T. Jones.

3) Mechanical properties of soil and pavement design - This subsection is led by Mr. E.H. Davis, B.Sc., and is concerned with methods of measuring the strength of soil, especially in relation to pavement design.

Part of the work of this sub-section is concerned with the development of the actual test methods. For example, the California bearing ratio test has been studied in relation to British conditions. It has been found that the saturation condition specified in the U.S.A. for this test in general gives thicker pavements than are required in Great Britain. The method of remoulding soil is being studied, and data are being obtained on the effect of dry density and moisture content on the C.B.R. of typical British soils.

Research on similar lines is being conducted on the unconfined compression apparatus, which is used in the Glossop and Golder design method and also on the plate-bearing test and on the triaxial compression test.

The relationship between the thickness of road construction and the strength of the subgrade as determined by the different mechanical tests is being studied by investigations of both concrete and bituminous roads where foundation failures have occurred. These investigations have proved invaluable not only in this particular connexion but also in giving a clearer insight into the effect of subgrade conditions generally on the behaviour of the road surface.

In addition to the studies of empirical methods of pavement design, described above, a mathematical approach is being made, and the first stage in this work has been the computation by Dr. L. Fox of the National Physical Laboratory of the stresses and displacements occurring in a two-layer system comprising pavement and subgrade. Equipment is being developed to check these computations experimentally, and in addition, possible methods of pavements design based on these computations are being studied in relation to available data from the investigations of failures. One of these methods is similar to that of Glossop and Golder, but the shear strength of the subgrade is compared with the shear stresses computed from a knowledge of the ratio of the elasticities of the pavement and subgrade. The subgrade elasticity is determined from triaxial tests made on cylindrical soil specimens.

4) Road drainage and stability problems - This sub-section is led by Mr. W.A. Lewis, B.Sc., and is concerned with studies of the drainage of subgrades, the consolidation of foundations, the settlement of embankments and the stability of slopes.

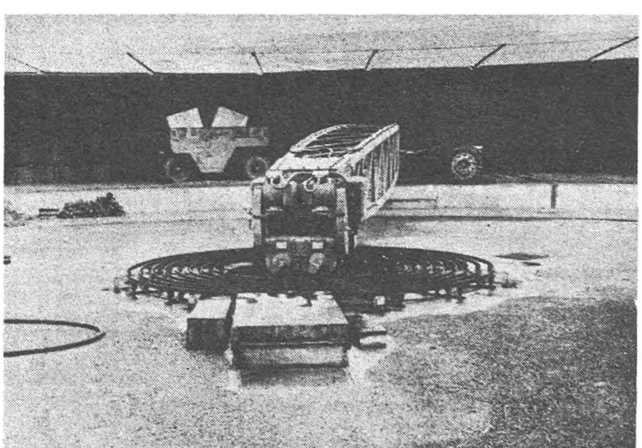
This sub-section has studied many cases where the failure of the road was attributable to the poor drainage of the soil foundation. In some of the cases studied, it appeared that the high moisture content of the subgrade was due at least in part to the subgrade being excessively wet when the road was constructed; the entry of water through porous or cracked surfacings has also been found to be responsible for many road failures. Studies of the damage of road surfacings caused by a prolonged drought in Great Britain in 1947 showed that the drying out of the subgrade from the verges reached almost to the centre of some 20-ft. wide roads.

Studies of embankment settlement have shown that serious differential settlement is liable to occur where there is a sudden change in the thickness of fill. These movements can be reduced by ensuring good compaction. An experiment is being undertaken on a chalk embankment to relate the settlement to the actual compaction of the filling.

5) Soil Compaction - This sub-section is led by Mr. F.H.P. Williams, M.A., and is concerned with all aspects of soil compaction.

Laboratory studies have been largely concerned with the development of a British Standard compaction test. It has been shown that the Proctor test can be successfully used on soil containing stone up to ¾ in. in size and that in the same test it is important to ensure that the three compacted layers of soil only just fill the mould. In the modified A.A.S.H.O. test it has been found that the same values of maximum dry density and optimum moisture content can be obtained by dropping a 15-lb. rammer through 12 in. instead of a 10-lb. rammer through 18 in., thus applying the same amount of energy to the soil. Future laboratory work will be concerned with developing a test which correlates better with British practical conditions.

Investigations of the performance of rollers and other plant are being made in the special covered track shown in fig. 6. The use of this track has enabled work to be carried on for the greater part of the year and has made it possible to obtain much better control than in open air tests. The trials so far completed were made with smooth-wheel and pneumatic-tyred rollers on a 9-in. loose layer of soil. At the time of writing two types of sheepsfoot roller are being studied. The pneumatic-tyred roller was found to have a satisfactory performance on all types of soil, when it was loaded suffuciently, while the smooth-wheel roller was found to be most suitable for compacting granular soils. Moisture content/dry density relationships have



Special Road Machine adapted for Soil Compaction experiments.

FIG. 6

been obtained with the rollers on a range of soil types and compared with laboratory compaction tests. This work has indicated that existing laboratory tests cannot be regarded as being more than tests for classifying soils according to their compaction characteristics.

Several investigations have also been made during the actual construction of earthworks to determine the most satisfactory method of compaction to be employed. It has been shown that a few simple trials can often enable improved compaction to be obtained at much less cost.

The future work of this sub-section includes the further study of the performance of compaction plant, the study of factors affecting their performance with the object of effecting improvements in design, investigations during the actual construction of earthworks and laboratory studies to be made with the object of developing tests which correlate better with practice.

6) Soil-cement stabilisation and Soil Surveys - This sub-section is led by Mr. S.B. Webb, B. Sc., it is concerned with improved methods of soil-cement construction, developing acceptance and control tests which will apply to conditions in Great Britain, and with developing the various available techniques for making soil surveys for roads and airfields.

The most important problems in soil-cement construction are probably those of thoroughly pulverizing the soil and mixing the cement with it. Various methods of studying the performance of different types of mixing plant have been tried out, and one series of tests has been made comparing laboratory mixing with that obtained with ploughs and disc harrows.

Several experimental lengths of soil-cement have been constructed, and their behaviour under different traffic and wheather conditions studied in relation to laboratory acceptance tests.

In Great Britain the crushing strength test has been widely used as a guide to the suitability of a soil for stabilisation with cement, and research has been carried out to find the most satisfactory test procedure. The effect on the crushing strength of such factors as the curing conditions, age of specimen, density and so on is being actively studied.

With regard to soil surveys, attention is being given to such problems as the design of improved methods of boring through difficult soils, the use of aerial photographs to identify soil types and such geophysical methods as the earth-resistivity test.

7) Colonial road problems - This work is conducted by Mr. H.W.W. Pollitt, B.Sc., and falls within the scope of the Soil Mechanics Section, as the majority of British colonial roads are of lowcost earth construction. Mr. Pollitt has recently spent some months in Nigeria examining road conditions in that country, and plans are being drawn up, in collaboration with Colonial Engineers, for carrying out research into some of the particular problems with which they are faced.

Publications

A list of published papers written by members of the Section is given in Appendix I. These are supplemented by several hundred confidential research notes.

Acknowledgement

This paper was prepared at the Road Research Laboratory of the Department of Scientific and Industrial Research, and is published by permission of the Director of Road Research.

PAPERS PUBLISHED BY MEMBERS OF THE SOIL MECHANICS SECTION OF THE ROAD RESEARCH LABORATORY.

1. A.H.G. Markwick. Soil problems in road construction. J. Instn civ. Engrs, 1929, 12 (7), 23-37.
2. A.H.D. Markwick. Cement stabilisation of soil. Roy. Engrs' J., 1939, 53 (June), 267-71.
3. A.H.D. Markwick. Road construction on peat foundations. Rds and Rd Constr., 1937, 17 (203), 343-5.
4. A.H.D. Markwick and G.C. Wilson. Observations of settlement of embankments. Surveyer, Lond., 1940, 98 (2528), 3-6.
5. A.H.D. Markwick and H.J.H. Starks. Stresses between tyre and road. J. Instn civ. Engrs., 1940-41, 16 (7), 309-25.
6. A.H.D. Markwick. Some economic factors relating to earthwork machinery. Rds and Rd Constr., 1941, 19 (217), 5-8.
7. A.H.D. Markwick. Soil classification and its bearing on soil stabilisation. J. Inst. Petrol., 1941, 27 (214), 313-28.
8. A.H.D. Markwick. Soil mechanics in road and aerodrome construction. J. Instn. civ. Engrs, 1942, 18 (5), 62-87.
9. A.H.D. Markwick and H.S. Keep. American equipment for earthwork construction on roads and aerodromes. Highw, and Bridges, 1943 9 (452), 1-2, 4; (453), 1, 3-4; (454), 1, 4.
10. A.H.D. Markwick and H.S. Keep. The use of low-grade aggregates and soils in the construction of bases for roads and aerodromes. Institution of Civil Engineers: Road Paper No. 9: London, 1943 (The Institution).
11. A.H.D. Markwick. Recent progress in stabilised base construction. Highw., Bridges and Aerodr., 1943, 10 (489), 1, 3, 10.
12. A.H.D. Markwick. The basic principles of soil compaction and their applications. Institution of Civil Engineers: Road Paper No. 16: London, 1945 (The Institution).
13. D.J. MacLean and D.W. Rolfe. Soil drainage by an electrical method. Civ. Engng, Lond., 1945, 40 (464), 34-7.
14. D.J. MacLean and D.W. Rolfe. An improved method of sampling soils in the field for moisture content determination. Rds and Rd Constr., 1945, 23 (265), 24-7.
15. K. Olpinski. A rapid field method for the determination of the moisture content of soils on constructional works. The Surveyor, Lond., 1945, 104 (2779), 237-8.
16. Soils, concrete and bituminous materials. A record of a course dealing with airfield construction given at the Road Research Laboratory, Department of Scientific and Industrial Research, July-August, 1943. London, 1946, (H.M. Stationary Office).
17. A.H.D. Markwick and S.B. Webb. Soil survey procedure and its application in road construction. London, 1946, (H.M. Stationery Office).
18. A.H.D. Markwick. Soil mechanics and road foundations. The Surveyor. Lond., 1946, 105 (2819), 79-83; (2820), 107-111; (2821), 121-2.
19. J. Rolfe. Determining the grain size analysis of foils. A rapid method for particles less than 0.002 mm in diameter. Rds and Rd Constr., 1946, 24, 414-5.
20. W. Eastwood. A theory of overland flow and its application to the design of drain inlet spacing on roads. The Surveyor, Lond., 1946, 105 (2848), 657.
21. D.J. Maclean and R.S. Bailey. Compaction

of soil. Full-scale investigations with various types of roller. I. Brickearth. Rds and Rd Constr., 1947, 25 (289), 12-6; (290) 55-9; (291) 88-90.

22. A.H.D. Markwick and A.F. Dobson. Application of electrosmosis to soil drainage. Engineering, 1947, 163 (4230), 121-3.

23. A Hunt. Compaction of soil. Full-scale investigations with various types of roller. II. Clayey-gravel. Rds and Rd Constr., 1947, 2, (291), 91-5.

24. D.J. Maclean. The application of Soil Mechanics to problems in road construction. J. Instn Munic. Engrs, 1947, 71 (11), 449-79, Discussion 466, 471-3.

25. D.J. Maclean and D.W. Rolfe. A laboratory investigation of electrosmosis in soils. Phil. Mag., 1946, 37 (275), 863-73.

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XII b 9 THE SOILS LABORATORY AT IMPERIAL COLLEGE UNIVERSITY OF LONDON

a) The address of the laboratory is:

Soils Laboratory,
Imperial College,
London, S.W.7. England.

b) The work carried out includes research, undergraduate and postgraduate teaching, and specialist consulting on engineering problems of research interest.

c) The laboratory, which was started in 1945, forms a section of the Department of Civil Engineering. The head of the Department is Professor A.J. Sutton Pippard, M.B.E., D.Sc.,

PLAN OF SOILS LABORATORY, IMPERIAL COLLEGE, UNIVERSITY OF LONDON

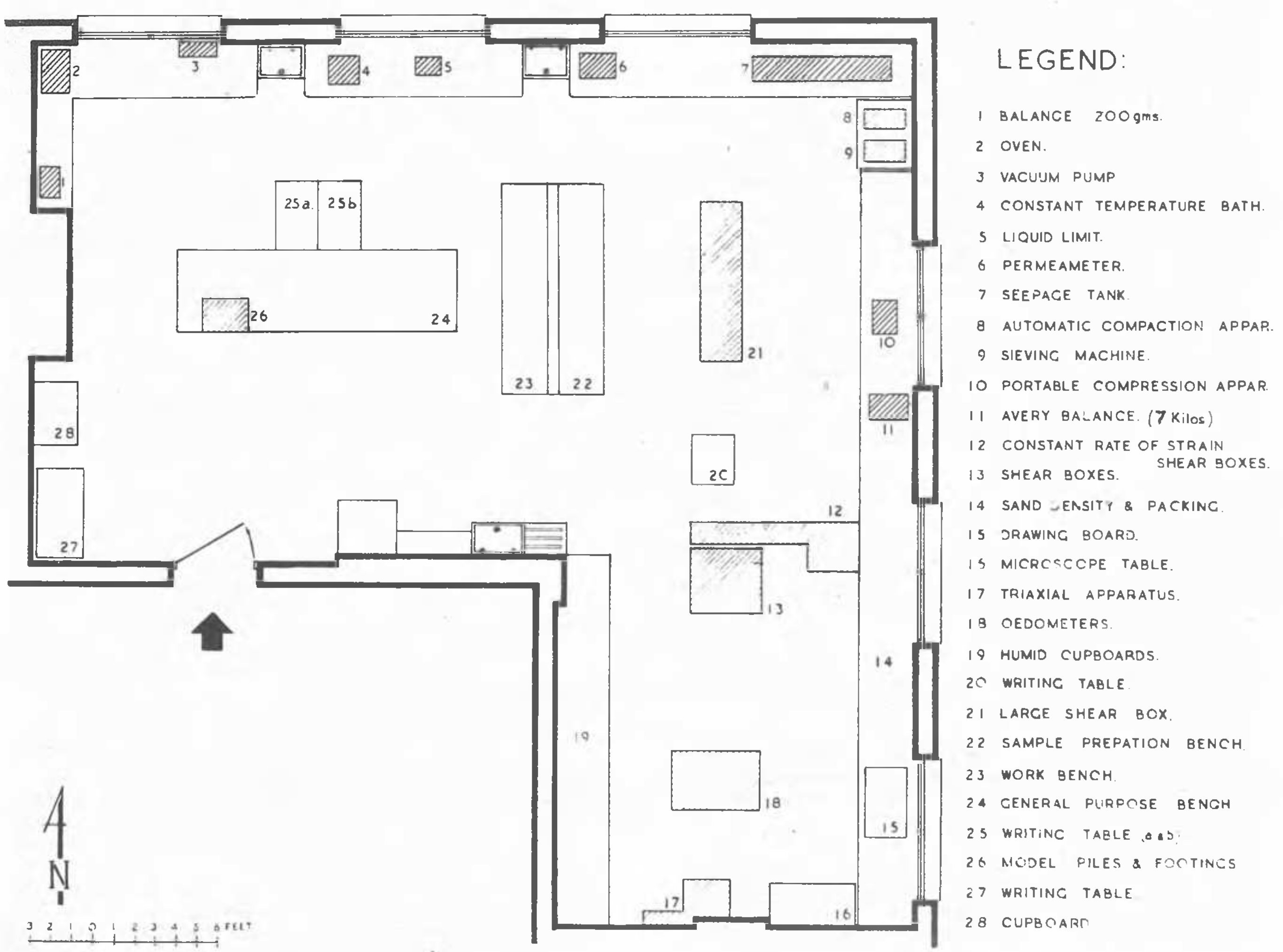

FIG. 1

M.I.C.E., F.R.Ae.S.

The soil mechanics section is under the direction of Assistant Professor A.W. Skempton M.Sc., A.M.I.C.E. F.G.S. who holds the post of Reader in Soil Mechanics in the University of London. Mr. A.W. Bishop, M.A., A.M.I.C.E., is Lecturer in Civil Engineering and supervises the laboratory and drawing office work.

In the Session 1947-48 the following post-graduate students are engaged in full-time research work:

J.J. Kolbuszewski, Dip.Ing.
R.E. Gibson, B.Sc.
Agnete Lund, Dip.Ing.
I.K. Nixon.
M.A.A. Hafez, B.Sc.

d) The number of personnel is:

2 permanent staff
1 laboratory assistant
5 full-time research students

e) The research programme includes laboratory work, mostly of a fundamental nature, and field work carried out in cooperation with consultants, contractors and Public Bodies. In addition specialist consulting work is undertaken where this involves problems of interest from a research point of view.

The following research work is being undertaken,

(i) Shear strength of soils, including saturated clays and silts, compacted clays and sands and gravels.
(ii) Effect of different methods of deposition and packing on the porosity of sands.
(iii) Model tests on the bearing capacity of piles and deep foundations
(iv) Design criteria for graded filters
(v) Field work on driving and bearing capacity of piles (with John Mowlem Ltd.)
(vi) Field work on softening of stiff-fissured clays in cuttings (with Southern Railway)
(vii) Field work on slips in river banks in the Fens (with River Great Ouse Catchment Board and Building Research Station)

Consulting work undertaken in the year 1947/48 includes the following investigations:

(viii) Foundation design for a grain silo on a deep deposit of estuarine strata (for Messrs. Unilever Ltd.)
(ix) Design of a runway for 120,000 lb wheel loads (for Sir Alexander Gibb and Partners)
(x) Seepage studies for a cofferdam (for John Mowlem Ltd.)

f) Undergraduates reading Civil Engineering take, in their 3rd year, a course in soil mechanics. This comprises one lecture a week during the three University terms, eight afternoons in the laboratory for each student, and a considerable amount of drawing office work including design problems of a straightforward nature. Postgraduates from other Universities who are specialising in Structures or Hydraulics also attend this course.

View of a part of the soils laboratory
Imperial College, University of London

FIG. 2

g) A plan of the laboratory is shown in Fig. 1 and a general view of some of the equipment is given in Figs. 2. The more important apparatus includes the following:

triaxial compression
3 constant rate of strain shear boxes (6 cm) with motor drive
1 constant rate of strain shear box (12 inches) with motor drive
2 direct shear boxes
2 portable compression machines
2 oedometers
automatic compaction apparatus
2 permeameters
apparatus for model pile and footing tests

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XII b 10 THE SCOTT & WILSON SOIL MECHANICS LABORATORY

GUTHLAC WILSON, S.M., B.Sc.

The Scott & Wilson Soil Mechanics Laboratory is situated at 57/59, Victoria Street, London, S.W.1. It is run as part of a Consulting Practice. The type of work so far carried out includes site investigations to obtain basic data for the design of buildings and roads, investigations of failures of retaining walls and foundations, and research projects.

The major research project so far undertaken is an investigation into the bearing capacity of screw piles and cylinders. This project includes theoretical investigations, model loading tests and full scale loading tests. The investigation of the elastic properties of sand, described in the paper submitted to this Conference by Wilson & Sutton, is a by-product of the above research project.

The Laboratory equipment has been limited to essentials and has been laid out as

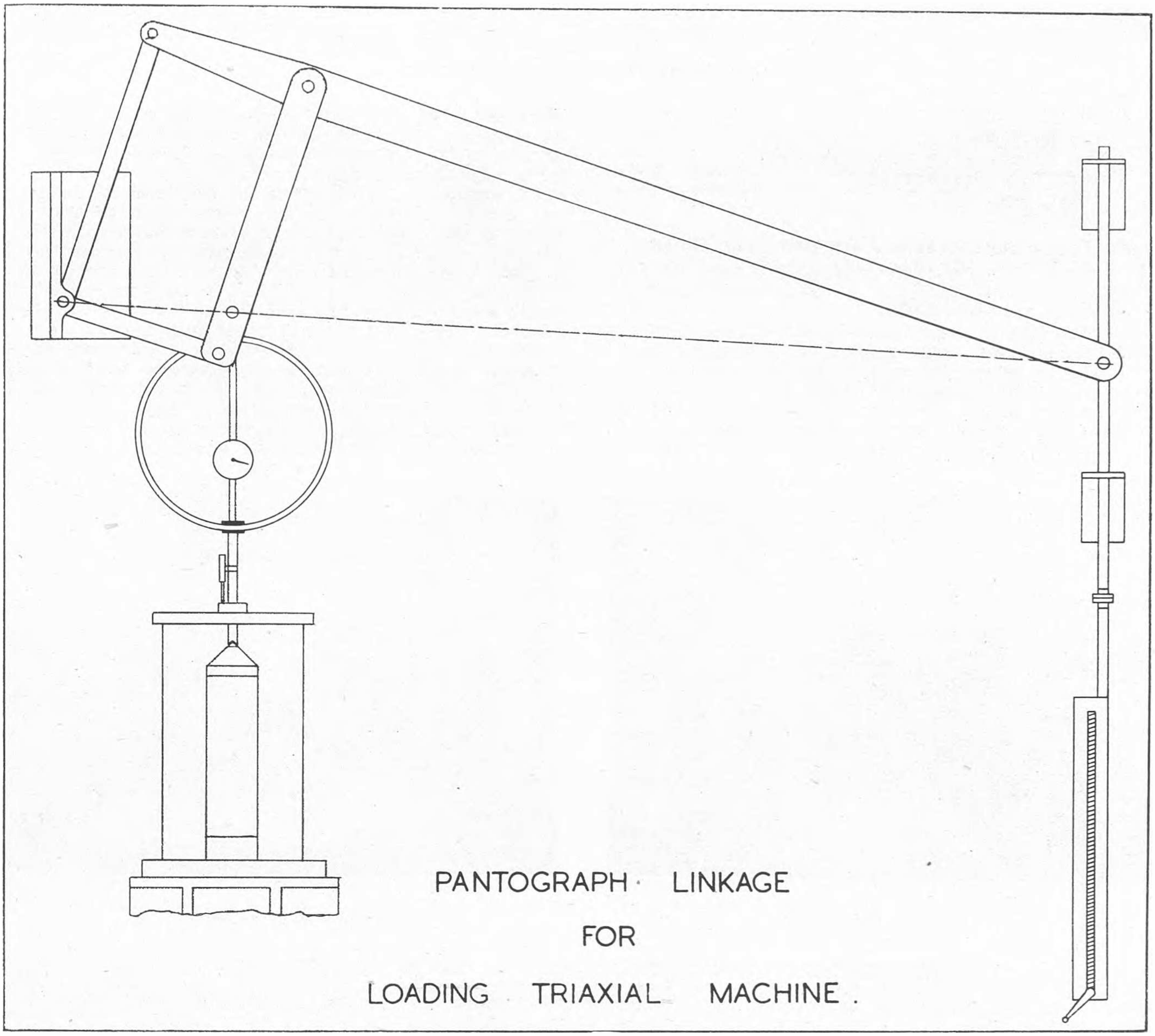

FIG. 1

compactly as possible on account of the extreme shortage of office space which exists in post-war London. The major items include apparatus for the following types of test:

Triaxial compression
Consolidation
Compaction
Sedimentation, by Casagrande aerometer apparatus, and standard sieves.
Atterberg Limits

The triaxial testing apparatus is wall-mounted and is loaded by "window-winder" working through a pantograph linkage.
This is illustrated in figure 1.

The samples tested are normally 2" in diameter and up to 6½" long, but the apparatus can be adapted to take samples 1½" or 2½" in diameter and can also be adapted to take a loading piston of the same diameter as the specimen, so that it is possible to carry out tests in which the intermediate principal stress is equal to the maximum principal stress.

The laboratory is at present in the charge of Mr. J.L.E. Sutton, B.A., who is responsible to Mr. Henry Grace, S.M., M.Sc, and to the Author. The junior staff comprises one recent graduate and one laboratory assistant.

Messrs. M.K. Roy, B.Sc. and G.M.J. Williams, B.A., have each previously had charge of the laboratory and are available for consultation and for work in the laboratory, as may be necessary.

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XII b 11

THE SOIL MECHANICS LABORATORY.

Cambridge University, England

1. NAME AND ADDRESS.

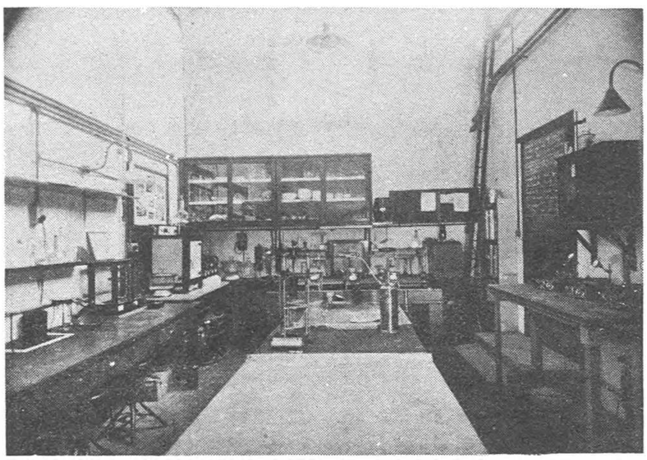
The Soil Mechanics Laboratory,
The Engineering Laboratories,
Cambridge University,
Cambridge,
England.

Head of the Engineering Laboratories: Professor J.F. Baker, O.B.E., M.A., Sc.D., D.Sc.

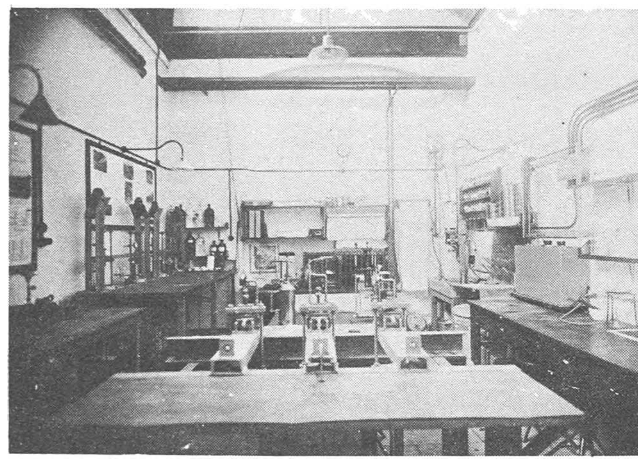
2. PURPOSE OF LABORATORY.

This Soil Mechanics Laboratory was instituted in May 1946. The present floor space available is only 308 sq.ft. A much greater floor space has been allocated to Soil Mechanics in the plane for the extensions of the Laboratories which have been prepared.

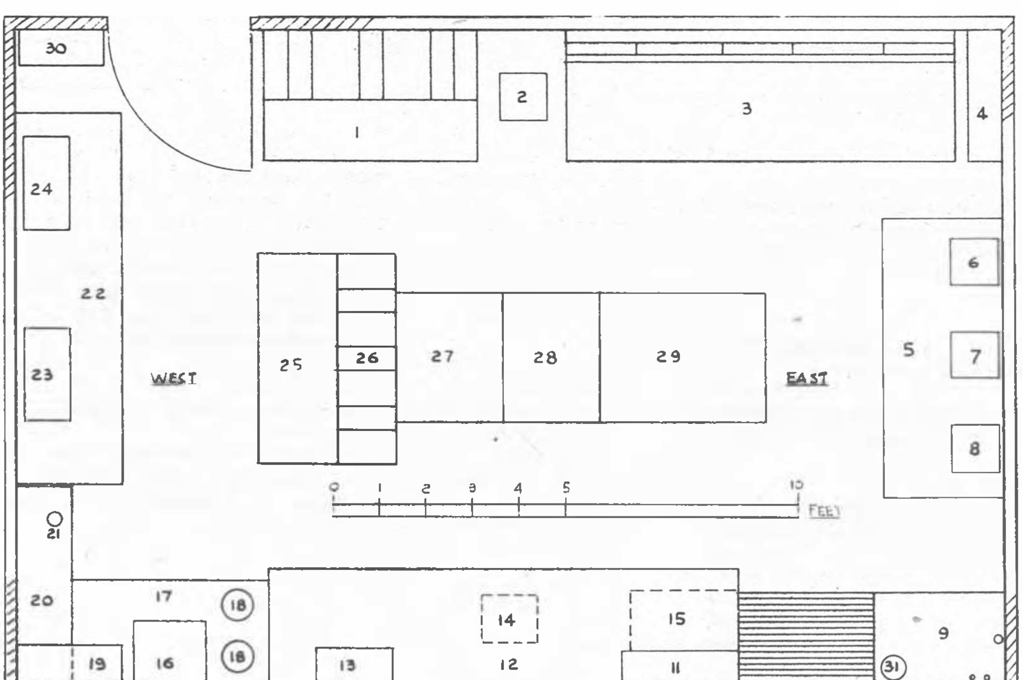
In 1946 the immediate need was for experimental apparatus for teaching purposes. At present two independent courses have been arranged to accommodate the large number of post war undergraduates. This is to ensure that every man graduating in Mechanical Sciences from Cambridge has at least an introduction to Soil Mechanics. The more extensive of the two courses is for students taking Group A (Civil Engineering) in Part II Mechanical Sciences Tripos. The numbers attending this course were fifty in 1946-7 and twenty in 1947-8. (Twenty is considered the normal optimum number). The experimental apparatus at present available for these courses include:- (i) 4 consolidometers, (ii) 3 strain control type shear boxes, motor driven, (iii) 3 stress control type shear boxes, (iv) Unicompression apparatus, (v) Permeability apparatus, (vi)



View of West End



View of East End



No	COMPONENTS
1	STRAIN CONTROL BOXES.
2	DRIVE MTG FOR SHEAR BOX
3	CONSOLIDOMETERS
4	SHELVES
5	TABLE
6	BEAM BALANCE
7	ANALYTICAL BALANCE
8	AVERY BALANCE 10 KGM
9	SINK
10	DRAINING BOARD
11	SEDIMENTATION THERMO BATH
12	BENCH
13	ANALYTICAL BALANCE
14	PUGMILL
15	SIEVES
16	OVEN
17	BENCH
18	DESICATORS
19	VACUUM FILTER BATTERIES
20	BENCH
21	HIGH SPEED STIRRER
22	BENCH
23	BEAM BALANCE
24	THERMOSTATIC BATH
25	) SHEAR BOXES
26	)STRESS CONTROL TYPE)
27	INDEX TESTS
28	UNI COMPRESSION
29	SAMPLE PREPARATION
30	SAMPLE TINS
31	ASCOT WATER HEATER

Dietert Compaction apparatus, (vii) Mechanical analysis - sieving, pipette and hydrometer, (viii) Casagrande apparatus for Atterberg Limit Tests, (ix) Particle Density determination.

A triaxial machine is being made but additional temporary accommodation will have to be found before it can be used.

The photographs and the plan show the arrangement of the Laboratory in October 1947.

The primary purpose of the laboratory is of course research. Much of the apparatus which has been made for teaching purposes has been constructed with research objectives in view. It is planned that research work will begin in 1948 on the shear strength of clays and the measurement of pore water pressure.

3. SOIL DYNAMICS RESEARCH.

With the support of the Nuffield Foundation a study of the soil dynamics of tillage has been started by measuring the component soil forces on a simple implement in motion. A number of force responsive elements, using both wire resistance strain gauges and deflection indicators, have been incorporated in the implement, and electromagnetic oscillograph apparatus having twelve channels has been designed and constructed for the continuous recording of the component soil forces on the elements. The recording apparatus has been specially developed to function reliably under severe field conditions.

Limited field trials have already taken place.

4. The present personnel are:-
A.H.A. Hogg, M.A., A.M.I.C.E. University Lecturer in Mechanical Sciences.
K.H. Roscoe, M.C., M.A. University Demonstrator in Mechanical Sciences and research worker in soil mechanics.
A.A. Wells, B.Sc., (Eng) Research Worker in Soil Dynamics.
One Laboratory Assistant.

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UNIVERSITY OF GLASGOW

James Watt Engineering Laboratories

A course of instruction in Soil Mechanics by means of lectures and laboratory experiments has formed an important part of the curriculum for students in Civil Engineering in the University of Glasgow since 1939.

The primary purpose of the lectures is to acquaint the students with the fundamentals of Soil Physics, and to show certain aspects of the application of these fundamentals to practical design and construction work. The laboratory experiments and the handling of soils by the students are intended to demonstrate these fundamentals, and to develop a judgment in the student concerning the degree of accuracy of the data obtained, and how best that data can be applied to the design of engineering structures.

An outline of the lecture course is as follows:

Soil origin and development; definitions and fundamental relations; soil structure and the effect of grain shape and grain size distribution; consistency and plasticity; capillarity, shrinkage and swelling of soils; shearing resistance; stress distribution; settlement analysis; bearing capacity of footings and piles; flow of water through soils; soil surveys and sampling; methods of compaction; landslides and stability of slopes; earth pressure on various types of structures; principles of design of dams.

The laboratory equipment has been designed and built up mainly for the purpose of introducing students to the techniques of soil examination and testing, and of providing facilities for research, but a limited amount of advisory work might be undertaken for outside bodies where the problems involve research for which the laboratory facilities are suitable. The apparatus at present includes equipment for obtaining small and large undisturbed soil samples; specific gravity determination apparatus; liquid limit device; sieves and hydrometers for grain size distribution measurements; unconfined compression testing machine; triaxial compression testing machine; constant rate of strain shear box; consolidation machine with devices for measuring pore water pressure; compaction apparatus for maximum density and optimum moisture content measurements; permeameters; apparatus to demonstrate influence of seepage forces in cohesionless soils; and ancillary equipment such as thermostatically controlled oven, vacuum pump, balances, etc. etc.

Research work is at present in progress on problems of consolidation and pore water pressure during consolidation.

Staff:
Professor G. Cook, D.Sc., F.R.S., M.I.C.E.; (Regius Professor of Civil Engineering and Mechanics and Director of the James Watt Engineering Laboratories)

Lecturers:
H.B. Sutherland, S.M., A.M.I.C.E., A.M.I.Struct.E., (At present on leave of absence to Graduate School of Engineering, Harvard University, U.S.A., as Research Associate in Soil Mechanics)

A.S. Thom, B.Sc., A.M.I.C.E.

Assistant and Research Student:
W. Bannatyne, B.Sc.

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XII b 13 THE SOILS LABORATORY OF R.H. HARRY STANGER

Name and address

Soils Laboratory of R.H. Harry Stanger, A M.I.C.E., M.I.Struct.E., Broadway House, Tothill Street London, S.W.1.
The Soil Mechanics Laboratory is one of a group of laboratories forming the building section of an engineering materials Consultant's business.

The chief purpose of the laboratory is advisory.

The staff consists of S.C. Bate, B.Sc., A.M.I.C. E., who is in charge, with one full time assistant, but the services of four others are available for part time work.

The laboratory itself is small, being of only about 300 sq.ft., but it is closely linked with the Cement and Concrete laboratories, and has free access to the general equipment of the other laboratories including Chemical, and the Mechanical Workshop.

The laboratory equipment includes the usual apparatus for carrying out classification tests, such as the Atterberg limits, Grain Size Distribution, Specific Gravity, Water Content, Density, Shrinkage and Compaction characteristics.

Apparatus is also available for carrying out most tests for the determination of mechanical properties which have come to be regarded as routine, with the exception of the triaxial compression test. Apparatus for the latter is under construction.

The methods of test adopted are generally in accordance with the A.S.T.M. Specifications.

Hand boring and sampling is undertaken by the laboratory staff, but for deeper borings specialist contractors are engaged.

The laboratory was established in 1939, and the main function fulfilled is to act in an advisory capacity to Consulting Engineers and Architects in the fields of civil engineering and building construction.

The work recently carried out includes the case of the settlement of a building founded on clay, and of a canal bank slip; also site surveys for several new school buildings.

Drainage of clay soils is being investigated, at present on a laboratory scale

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XII b 14 STATEMENT OF ORGANIZATION OF SOIL MECHANICS AND GEOPHYSICS LABORATORY

of

GROUND EXPLORATIONS LTD.

The name of the Organization is GROUND EXPLORATIONS LTD. with registered office at 75, UXBRIDGE ROAD, EALING, LONDON, W.5.

The purpose for which the Company was formed was to act in an advisory capacity to Civil Engineers, Architects, and others with regard to investigations of the nature of the ground. For this purpose the company has a Soil Mechanics Laboratory and its own Drillers who are conversant with the modern technique of obtaining undisturbed core samples. Advice is given on any problem relating to soil mechanics. Research work has been carried out including work on the bearing capacity of footings on non-homogeneous cohesive soils.

In addition to this type of work, exploratory borings are undertaken for such purposes as prospecting for coal and other minerals.

Electrical resistivity methods of geophysical prospecting are used, generally with either the Wenner or the potential-drop-ratio configuration of electrodes; information is given regarding thickness of overburden, extent, depth and thickness of seams of minerals and gravel, location of fissured areas of chalk, limestone etc. for water supplies.

Specialist personnel are:
E. Wilson, A.M.I.Mech.E., A.I.Struct.E.,
S.J. Button, B.Sc., A.Inst.P.
R.M. Boorman, B.Sc., A.R.C.S., Inst. P.

E. Wilson (Mr.) has a wide experience of Drilling of all types. He has also been engaged on geophysical prospecting for 17 years, and has assisted in the development of some of the latest forms of electrical resistivity instruments.

S.J. Button (Mr.) spent nearly 5 years in the Soil Mechanics Laboratory of the Building Research Station, Department of Scientific and Industrial Research. For the past 3 years has been in charge of Soil Mechanics Laboratories working in an advisory capacity, and has also had experience of Drilling and Geophysical exploration.

R.M. Boorman (Mr.) is a Geophysicist, and has made a number of succesful Geophysical surveys in this country and abroad. He has been actively engaged in developing new instruments for this kind of work. He is also engaged on Soil Mechanics.

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SOIL MECHANICS SECTION

of

LE GRAND, SUTCLIFF AND GELL, LTD.

a) Name and address of the Company.
LeGrand, Sutcliff & Gell Ltd.,
Southall,
Middlesex,
ENGLAND.

b) Purpose.
One of the main functions of the Soil Mechanics Section of the above company is acting in an advisory capacity to Consulting Engineers, Contractors, Government and Local Government Departments, Public Utility Service Bodies etc. Our research activities have been confined to collaboration with Government Research Bodies, and to the solution of specific problems arising in connection with site investigations.

We are fully equipped for carrying out large scale site investigations, and besides the orthodox methods of exploratory boreholes we have a number of instruments for carrying out electrical resistivity surveys. Although the bulk of our work is confined to Gt. Britain, we have completed many site investigations overseas.

Our laboratories are adequately equipped with modern instruments for complete laboratory investigations of soils and soil properties.

The services offered by our soils department include comprehensive Engineering reports based on the results of the tests, and embodying practical comments and presentation of data in a form required for foundation design.

The most common problems submitted for our consideration include the determination of bearing capacity, settlement, shrinkage, creep and permeability of soils, earth pressure and suitability of soils for piling, stabilisation and ground water lowering, grading of filters etc.

These problems have arisen in connection with a wide variety of projects including roads and runways, bridges, buildings, earth retaining walls, jetties and dock walls, chimneys, dams, furnaces and refrigators, piling etc.

c) Names and Qualifications of Staff, specialists etc.
H.M. Gell, M.C., M.I.C.E., M.I.MECH.E.
J.P. LeGrand, M.I.C.E., M.I.MECH.E.
H.A. Hetherington, A.M.I.C.E.
E.T. Hanrahan M.Eng., A.M.I.C.E., A.M.I. STRUCT.E.
P.R. Sánsom.
A.G. Fisher.

d) Number of Personal.
15 No.

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ROAD AND RUNWAYS (ENGINEERS) LTD.

a) Name and Address:
Roads & Runways (Engineers) Ltd.
Head Office: 32 Savile Row, London, W.1.
Laboratory: 310 Wandsworth Bridge Road, London, S.W.6.

b) This Company was formed to undertake among other engineering objects soil surveys, field and laboratory tests required in the application of Soil Mechanics to the investigation, design and construction primarily of roads, airfields and foundation work. The Company acts as an advisory body in the preliminary stages of a proposed project, but also assumes responsibility for contract work during construction. It is especially qualified to engage on problems relating to soil stabilization and the use of local materials for pavement construction, again being willing to undertake control work on the actual contract. While the Company commenced activities in Britain, work is now being carried out in Egypt and in the African Colonies. In addition services are also provided for location surveys and for the testing of bituminous surfacing materials and advice on this, including the plant aspect.

c) Staff concerned with Soil Mechanics Work:
C.T. Mitchell. B.C.E. (Melbourne)
G.C. Wilson, B.Sc. (Eng.) A.M.I.C.E.
F.L. Cassel, A.M.I.C.E., Dipl. Ing.
A. Hunt, M.Sc.
K. Olpinski, Dipl. Ing.
A.Ch. Ling, Chemist.

d) Number of permanent personnel: 18.

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CIVIL AND MUNICIPAL ENGINEERING DEPARTMENT

UNIVERSITY OF LONDON, UNIVERSITY COLLEGE

REPORT ON SOIL MECHANICS COURSES AND LABORATORY EQUIPMENT

P. L. CAPPER, T.D., M.Sc., A.M.I.C.E., A.M.I.Struct.E.

Instruction in Soil Mechanics was initiated in 1938 in the Civil and Municipal Engineering Department of University College, when a short course of lectures was delivered to final year Civil Engineering students. A start was made for the installation of Soil Mechanics testing apparatus in the Chadwick Civil and Municipal Engineering Laboratory. The war intervened, and owing to the evacuation of the College to Wales, further development was held up until 1945. The Laboratory had meanwhile suffered considerable war damage, but the re-equipment and expansion of the Soil Mechanics Group has recently made considerable progress.

Purpose. The lecture and laboratory courses are designed to give students of Civil Engineering a sound fundamental knowledge of Soil Mechanics, its application to civil engineering work, methods of testing, and interpretation of the results of tests. Plans have been made for research work to be undertaken by members of the staff and postgraduate students. The work of the Group is in close touch with the Road Research Laboratory, the Building Research Station and other organisations.

Staff. The Soil Mechanics Group is part of the Civil Engineering Department of the College, which is under the direction of Professor H.J. Collins, M.C., M.Sc. M.I.C.E., M.I.Mech.E., M.I.Stuct. E., A.M.Am.Soc.C.E., Chadwick Professor. Mr. P.L. Capper, Senior Lecturer in Civil Engineering, is in charge of the Group.

Equipment. The laboratory equipment includes the following:

Apparatus for mechanical analysis, specific gravity of particles, density and moisture content.
Liquid limit device;
Shear box machine;
Unconfined compression machine;
Consolidation apparatus;
Triaxial compression machine;
Proctor compaction apparatus;
California bearing ratio apparatus;
Model retaining wall for demonstrating plane of rupture.

Various other apparatus is on order, including a permeameter, model apparatus for flow net investigation, etc.

A constant temperature room in the Laboratory which was destroyed by enemy action has been rebuilt, but the thermal apparatus has not yet been restored.

Undergraduate Courses. The course for final year Civil Engineering students comprises lectures on classification and identification of soils, soil properties and application of Soil Mechanics to earth pressure, stability of foundation and road construction; laboratory work on the simpler standard tests.

The second course is for 4th(suspense) year and postgraduate students, and consists of lectures on more advanced aspects of the subject, the working out of practical problems, and more advanced laboratory work.

Research. It is proposed to institute research work on several problems, including the following;

1. Investigation of the effects of temperature variation on the results of standard soil tests.

2. Comparison of various penetration tests and their co-relation with strength tests.

3. Application of vibration methods to compaction tests.

The photo-elastic laboratory in the Mechanical Engineering Department, originally set up by the late Professor E.G. Coker, F.R.S., is being modernised and extended, and it is hoped to investigate by this method some problems on stress distribution in semi-plastic soils and in two- or three-layer materials.

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UNIVERSITY OF LONDON KING'S COLLEGE

King's College is one of the Incorporated Colleges of the University of London and has a Faculty of Engineering from which a total of approximately 45 students graduate each year in the three branches of Civil, Mechanical and Electrical Engineering.

Since 1946 the subject of Soil Mechanics has been included as part of the final year course for Civil Engineering students and a laboratory has been established. A course of 30 lectures is delivered in the year and each student devotes approximately 30 hours to practical work in the laboratory each year. The course is a general one and ranges from the origin and analysis of soils, methods of measuring soil properties, etc. to the application of the results of the tests in the design of structures.

The main function at present of the Soil Mechanics laboratory is as an aid to teaching, but a limited amount of research is carried out in it as well. Each final year student undertakes an "individual problem" or project of research on which a report is presented at the end of the year. At present there are four such students engaged on research on Soil Mechanics problems. Plans are now under consideration for a new and larger laboratory and when this is completed it will be possible to accommodate more postgraduate students working in this field.

The laboratory equipment includes shear boxes, triaxial machine, unconfined compression machine, sieves and mechanical analysis equipment, compaction test equipment, Liquid Limit device, density measuring apparatus, California bearing ratio equipment, 5000 lb. testing machine, balances and ancillary apparatus. Larger capacity testing machines are available in the nearby materials laboratory if required. Thus it is possible to carry out any of the standard soil tests in the laboratory.

The Civil Engineering laboratories are under the general direction of Professor A.D. Ross, Ph.D., A.M.I.C.E., F.R.S.E., and the Lecturer in charge of Soil Mechanics is Mr. Kevin Nash, B.A., B.A.I., A.M.I.C.E.I., formerly on the staff of the Road Research Laboratory, Middx., England.

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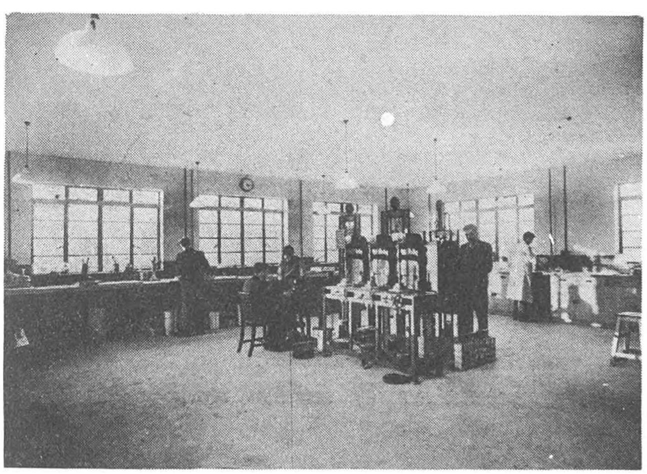
XII b 19 GEORGE WIMPEY AND CO. LTD., CENTRAL LABORATORY. LANCASTER ROAD. SOUTHALL, MIDDLESEX, ENGLAND

SCOPE AND PURPOSE.

The above Laboratory was established as an advisory and research institution. The work is partly concerned with the development and improvement of technique in Civil Engineering construction for the main organisation of the Company, and partly with site exploration for the design of foundations and other constructional works for consulting engineers and other authorities.

The soil mechanics laboratories, one of which is shown in Fig. 1, are fully equipped with all the testing equipment normally employed. Special equipment is also being developed for certain tests. Other sections of the main laboratory deal with concrete, bituminous materials, building construction and chemical analyses, and close collaboration is maintained in dealing with related problems.



Part of the main Soil Mechanics Laboratory.

FIG. 1

Site exploration for the design of foundation and other below-ground constructional works, and soil surveys for road and airfield projects are undertaken both in Gt. Britain and abroad with an extensive range of soil boring and sampling equipment, including diamond drilling plant for proving rock formations and for mineral prospecting. When conditions are favourable, electrical resistivity apparatus is used to determine changes in level of strata between boreholes. Sea borings to provide data for the construction of docks and harbours are also made.

Field tests such as plate loading tests and the measurement of stresses in trench supports are made in conjunction with fully equipped mobile laboratories. The latter are also used in connection with the control of the compaction of earthworks and stabilised soil schemes.

Among the many soil investigations which have been carried out, may be included, the cause and prevention of slips in various embankments and cuttings, the most interesting of which was extensive slipping of a bank over 100 ft. high adjoining a ship building yard, and in which the failure was traced to the presence of thin horizontal sand seams connecting with a reservoir of water at the top of the bank. Also of interest was a slip on an opencast coal site in which the overburden was sliding on a thin seam of soft fireclay.

The cracking of houses built on slopes on London Clay have been investigated and remedial measures suggested.

Numerous estimates of settlement have been made in connection with the design of heavy foundations to such structures as cement silos, heavy crane and machinery installations, factory buildings, oil tanks, reservoirs, gas holders, etc. Recommendations based on soil mechanics tests and civil engineering experience have also covered various subjects such as the design of sheet piling, depths of bearing piles, the possibility of attack by sulphates, and the efficiency of ground water lowering methods in specific soils.

Work on the construction of roads and runways has included investigations on the compaction of brickearth and hoggin fill by various types of roller at London Airport. Recommendations have also been made on soil stabilisation technique for a number of secondary roads in Gt. Britain, and for various other projects abroad, particularly in the Middle East.

Research work has so far been restricted mainly to the improvement of methods of boring, sampling and testing, to methods of compacting fill areas and problems connected with the estimation of settlements of loaded areas. Various other minor researches have, however, formed an integral part of the solution of many of the soil mechanics problems on which advice has been given.

STAFF PERSONNEL.

L.J. Murdock, Ph.D., M.Sc.(Eng.), A.M.I.C.E.
General administration and special study of problems related to the settlement of structures.

M.J. Tomlinson, A.M.I.C.E., A.M.I. Struct. E.
Technique in the construction of civil engineering works..

S.F. Searchfield.
Site organisation and planning.

S. Rodin, B.Sc. (Eng.).
Research on methods of sampling and testing, consolidation and ground water lowering.

J.B. Holt, B.Sc., A.M.C.T.
Geology and soil stabilisation.

C.F. Robinson, B.Sc. (Eng.).
Roads and runway construction.

A.G. Forster, B.Sc.
Field engineer - overseas investigations.

S. Scruby, B.Sc.
Resistivity surveys.

The total number of staff personnel employed on soil mechanics work is twenty two.

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XII b 20 SOIL MECHANICS LABORATORY OF THE DIVISION OF THE CHIEF SCIENTIFIC ADVISER, MINISTRY OF WORKS

(The Thatched Barn, Barnet, Hertfordshire, England.)
J. N. McFEETERS

This laboratory was founded in 1942 within the Ministry of Aircraft Production, principally to supply information on soils in connection with the Ministry's Airfields and runways. Certain contracts carried out in 1943 on behalf of the Ministery and serviced by this laboratory, were possibly the first in the United Kingdom in which controlled compaction on a large scale was specified and obtained. The laboratory's work was soon extended to factory foundations, stability of slopes in embankments, and investigations in connection with drop-hammer and Ceco-Stamp foundations.

In December, 1945, the laboratory was transferred to the Division of the Chief Scientific Adviser, Ministry of Works, in order to be available for investigations in connection with the Ministry's Programme of post-war building. Also included in its terms of reference are investigations on behalf of any other Ministry of building or construction projects in which that Ministry has a direct concern.

In April, 1946, the laboratory was moved from London to more extensive premises near Barnet, Hertfordshire. A "wet" and "dry" laboratory are equiped to carry out all normal soil mechanics tests, with separate office accommodation and land available for field tests. Borings are usually carried out by contract with site supervision, but the laboratory has in addition its own boring team capable of taking 6 in. dia. lined borings to 100 ft. depth or shallower hand auger borings.

The present staff consists of a Senior Civil Engineer, an Engineer, three Assistant Civil Engineers, an Experimental Officer, and two laboratory assistants in addition to secretarial staff, a boring foreman and labourers. Workshop facilities are available.

Among the principal heavy building projects referred to the laboratory for site investigation have been the National Aeronautical Establishment at Bedford, Government Offices in Whitehall and large factories at many other sites. Other investigations have included a site for a small dam, landslips, proposed sites for hollow clay block production, many building estates, problems connected with the reinstatement of open cast coal sites and with mining subsidence, airfields (for Ministry of Supply and Ministry of Works), County schools, etc.

Although research does not normally form part of this laboratory's work and is left to the Department of Scientific and Industrial Research, some experimental research on concrete runway slabs has been carried out under heavy loadings. Officers of the laboratory sit on various technical committees, including Codes of Practice, British Standards, the Soil Mechanics and Foundation Committee of the Institution of Civil Engineers and the Soils Committee of the Road Research Board.

Work in progress includes an investigation of the site of a proposed new town at Mobberley, the Bedford N.A.E., mentioned above, and several factories, airfields, and schools.

The writer has been in charge of the laboratory since its inception with Mr. F.S. Strongman, as his Chief Assistant. Reports are made to Mr. F. Webster, M. Eng., M.I.C.E., Deputy Chief Scientific Adviser, Ministry of Works, who is in general control under the Chief Scientific Adviser, Sir Reginald Stradling, C.B., F.R.S., D.Sc., M.I.C.E.

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SOIL MECHANICS LABORATORIES IN SWITZERLAND

A) a) Name and address:
Laboratory for Hydraulic Research and Soil Mechanics of the Swiss Federal Institute of Technology, Zurich, Switzerland, Gloriastrasse 37, Zurich 7 (State Institution, founded in 1929).

b) Purpose:
1. Teaching (courses in foundation engineering, Soil mechanics and Snow mechanics, engineering geology of soils)
2. Research
3. Advisory institution (foundation, roads, runways, slides, earth dams, etc.)
4. Centre of information and documentation for soil mechanics problems and geology of the subsoil.

c) Staff: Director: Mr. E. Meyer-Peter, Professor of Hydraulic work, waterfalls and foundation at the Swiss Federal Institute of Technology, Zurich.
Assistant-Director: Mr. R. Haefeli, Professor for soil mechanics and Snow mechanics at the Swiss Federal Institute of Technology, Zürich
Civil engineers: Mr. L. Bjerrum
Mr. Aug. Müller
Mr. W. Schaad
Mr. Ch. Schaerer
Mr. C. Stamm
Mechanical engineers: Mr. G. Amberg
Geologist: Mr. A. von Moos, Ph.D.

d) Subaltern Staff: 1 technicien
1 drawer
1 mechanics
1 laborant
1 typ writing girl.

B) a) Name and address:
Soil Mechanics Laboratory of the Institute of Technology of the University of Lausanne (Switzerland), 67, Rue de Genève, Lausanne. State Institution, founded in 1933.

b) Purpose:
1. To enlarge and facilitate the instruction of the Institute of Technology (courses in foundation engineering and soil mechanics).
2. To carry out academic and scientific research fitted for the development of foundation engineering technics.
3. To assist Offices of Technical Studies, administrations and general building and public works contractors in carrying out studies in foundation soils, engineering structures, houses, roads, airports, runways, etc.
4. To constitute a public centre of information, documentation and culture pertaining to the foundation engineering technics.

c) Staff: Director: Mr. A. Stucky, professor of Hydraulic Works, Water Falls and Foundation lay-outs at the Institute of Technology, also director of Hydraulics Laboratory of the Institute of Technology.
Assistant Director: Mr. D. Bonnard, Professor of Hydraulics and Soil Mechanics at the Institute of Technology, also assistant-director of the Hydraulics Laboratory of the Institute of Technology.
2 Civil-engineers: Mr. J. Bonjour
Vacant
Subaltern staff: 2 techniciens
2 mechanics
1 draughtsman
2 laboratory assistants.

a) Name and address of the Institute:
Dr. geol. L. Bendel, civil-engineer, Alpenquai 33, Luzern, Member of the National Research Council, Highway Research Board, Department of Soil Investigation, Washington DC.

b) Purpose:
Teaching as lecturer at the University of Lausanne. Advising Institution for the administrations, for court and contractors.

c) Name of staff personnel:
Eng. G. Schlumpf, chief of the laboratory
Eng. O. Maurer, specialist for fieldwork
Eng. W. Hassler, specialist for geoseismical research
Eng. O. Heuberger, specialist for geoelectrical research.

d) Number of personnel: 4 to 6

a) Name and address:
Solexpert: Research and consulting office for applied soil mechanics, Limmatstrasse 36, Zurich (Switzerland).

b) Purpose: research, advisory institution.

c) Director: Mr. J.P. Daxelhofer, Civil engineer.
Laboratory chief: Mr. H. Bolomey, Civil engineer.

d) Number of personnel: 3 and 2.

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SOIL MECHANICS LABORATORY

TECHNICAL UNIVERSITY. BUDAPEST. HUNGARY

Name of institution, organization, its location and year established:
Soil Mechanics Laboratory, Chair of Railway construction, Technical University, Budapest. Hungary, XI. Müegyetem. Established: 1930.

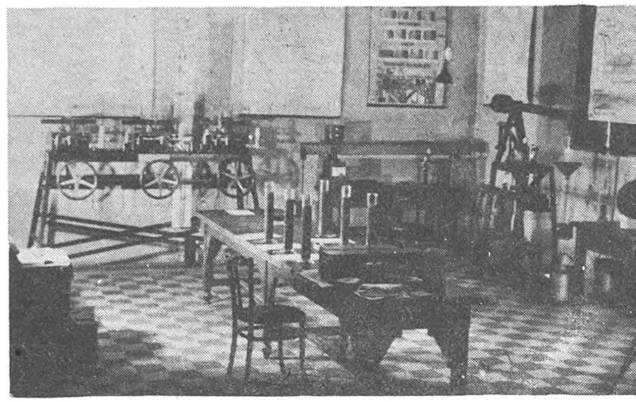
Head of Laboratory:
Dr. József Jaky, Ordinary Professor, Technical University.
Regular Staff: 1 instructor 3 assistants
Temporary Staff according to requirements.

FIELD OF ACTIVITY.

1. Instruction civil engineering students in elements and fundamentals of soil.characteristics and of soil tests. Obligatory laboratory course in the seventh semester, demonstrations to the courses of Soil Mechanics, and Foundations. Graduate course in Soil Mechanics and Foundations. Advanced studies for Doctor's Thesis.

2. Research work. Following research tests have been carried out in the Laboratory or are partly in progress:
Compression and shearing tests applying great pressures. Tests to determine the tensile strength of soils. Test to determine physical properties of bitumen (compressive strength, angle of internal friction, compression at various temperatures). Cleft resistance tests. Studies on capillary and permeability effect in soils. Settling of loose soils under the influence of water level oscillation. Swelling studies on clay samples. Settlement observations on existing buildings. Theoretical investigation of the equilibrium of supported and free earth masses. Law of strain and stress in soils of three phases, in state of unconfined and confined compression.

3. Consulting work. Soil testing for



public roads. Soil investigations for landslides, design of drains. Earth pressure and mountain mass pressure problems, retaining wall and tunnel design. Investigations of foundation problems. Consulting in foundation problems of buildings and manufacturing plants, bridges and water tanks.

The laboraotry is equipped with all instruments used in international routine tests. Separate laboratory for students to receive 20 students at a time. Total floor area: 250 m. 7 loading machine of 500 kg capacity, one of 4500 kg capacity, 1 Taylor's shearing apparatus, 1 Casagrande's shearing apparatus, Vandervoort's loading machine, oedometers for testing gravels, triaxial compression apparatus, cell apparatus, penetrometer to test soils for compactness, determination of permeability in falling head and constant head permeabimeters and from oedometric test.

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THE SOILS AND FOUNDATIONS DIVISION OF THE "INSTITUTO DE PESQUISAS TECNOLÓGICAS" IN SÃO PAULO (BRAZIL)

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Submitted by the Soils and Foundations Division of the I.P.T. (Brazil)

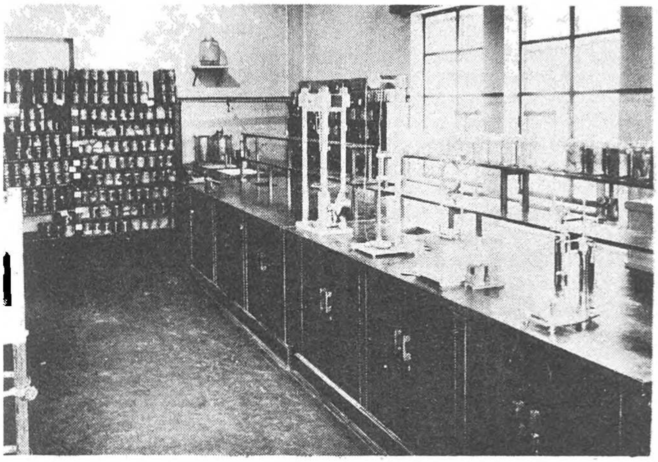
INTRODUCTION

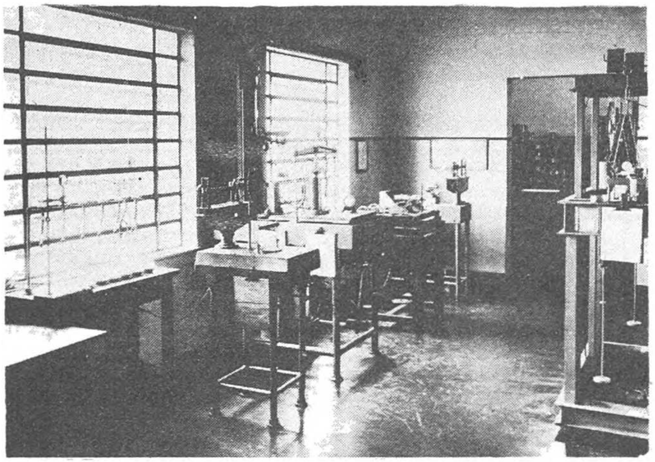
The "Instituto de Pesquisas Tecnológicas" (I.P.T.) (Institute for Technological Research) is a government institution of the state of São Paulo, attached to the University of São Paulo (Brazil). It was created for the purpose of doing research and routine tests in several fields of Technology to meet both private and public demands and to broadcast the latest developments of Technology in the country.

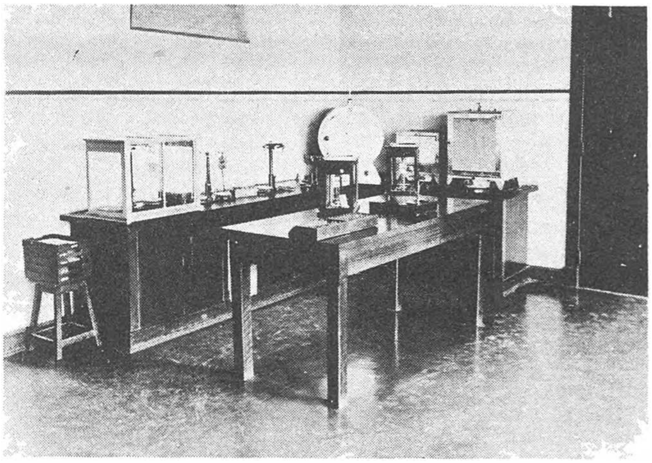
ACTIVITIES OF THE SOILS AND FOUNDATIONS DIVISION.

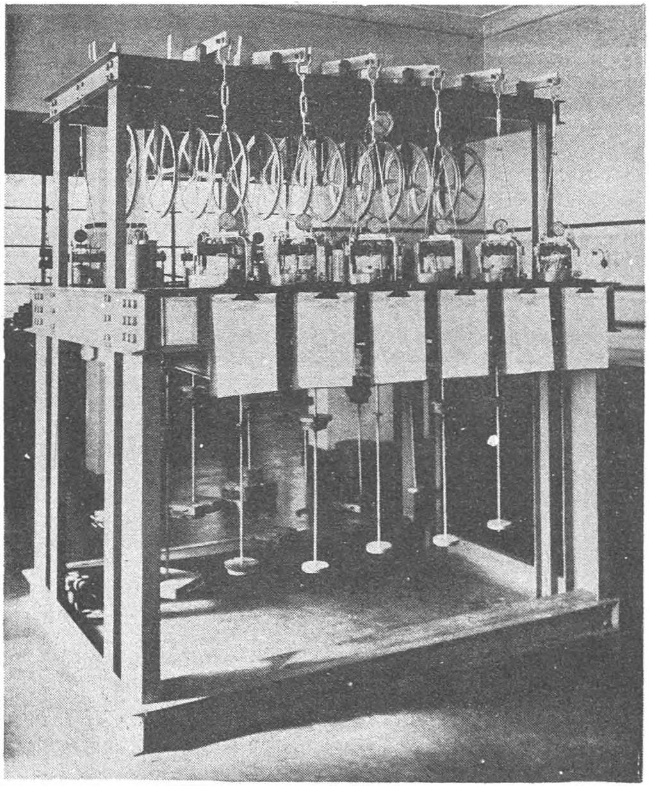
The main purpose of the Division is to advise public and private organizations in connection with problems of foundation and earthwork engineering. The major demand has been on building foundation problems in the city of São Paulo. During its nine years existence this Division has carried out soil exploration in about 400 sites with about 42 000 m of borings, and made tests on about 10 000 samples; it has also performed about 300 load tests and measured settlements of 18 structures of major importance.

The Soils Division has organized courses on Soil Mechanics and its Applications with the sponsoring of various engineering organizations.









PERSONNEL OF THE DIVISION

Chief engineer - Milton Vargas
Assistant engineers - Ernesto Pichler
Lauro Rios
Francisco Pacheco Silva
A.D.F. Nápoles Neto
Carlos R. Ladeira

The Division employs 38 more, including draughtsmen, office and laboratory people and field workers, and about 6 engineering students.

LABORATORY EQUIPMENT

The laboratory performs mainly all tests covered by the A. Casagrande publication "Soil Testing for Engineering Purposes". These tests include the determination of soils grain size distribution by the combined sieve and hydrometer method; water content, Atterberg limits and specific-gravity determinations; consolidation, permeability, unconfined and tri-axial compression, direct-shear and compaction tests. All test procedures follow closely the above mentioned publication. Laboratory and office space of the Division are respectively 150 m2 and 80 m2. The equipment comprises mainly:

Consolidation tests:
- 1 loading frame for 12 rings of Ø 10.7 cm
- 12 rings of Ø 10.7 cm
- 3 rings of Ø 20.0 cm

Compression tests; machines for controlled strain increments:
- 1 for unconfined and consolidated quick triaxial tests
- 1 for unconfined compression tests.

Compression tests; machines for controlled stress increments
- 1 for triaxial tests
- 1 for unconfined compression tests

Direct shear tests:
- 1 machine for controlled shear-stress increments
- 1 machine for controlled shear-strain increments

Compaction tests:
Several cylinders and tampers for both standard and modified Proctor test

CBR tests:
- 1 complete set

Classification tests

Sieves, hydrometers, liquid limit devices, picnometers.

Boring, loading test and settlement observation equipment - The Division is equiped to maintain four 2" casing boring and two 6" casing undisturbed sample boring crues. The 2" casing boring is a dry-sample boring x) equipment. The 2" casing borings are supplemented by measuring the penetration resistance of a split-spoon sampler. This resistance is measured by the number of blows of a 60 kg weight falling 75 cm to make the sampler penetrate about 30 cm; the sampler has internal and external diameter of respectively 37 and 46 mm. The undisturbed sample equipment use Casagrande-Mohr-Rutledge, M.I.T. - piston and Ivanoff samplers.

Loading test equipment comprises 10 hydraulic jacks, with loading capacity ranging from 30 to 200 tons, micrometers, large dimension circular and square plates (from 0.5 to 1.0 m2) and all supplementary material.

The Division has also two sets of Terzaghi's precision water levels and a precision optical level for measuring structure settlements.

PUBLICATIONS OF THE DIVISION

The following papers on Soil Mechanics have been published by members of the Soils and Foundations Division of the I.P.T.:

1) Grillo, O. - "Pressões do solo sôbre escorementos o revestimentos de subterrâneos" - 1937, São Paulo - Separata do Boletim do Instituto de Engenharia.
2) Grillo, O. - "Secção transversal de Auto-Estradas" - Separata do Boletim do D.E.R. - 1940, São Paulo.
3) Vargas, M. - "Sôbre a aplicação da geofísica à exploraçao do subsolo" - Separata do Boletim do D.E.R. - 1941 São Paulo
4) Vargas, M. - "A capacidade de carga das fundações diretas" - Separata do Boletim do D.E.R. - 1942 - São Paulo.
5) Pichler, E. - "A petrografia e os ensaios tecnológicos das rochas" - Separata do Boletim do D.E.R. - 1942 - São Paulo.
6) Grillo, O. - "A Mecânica dos Solos na técnica rodoviária" - Separata do Boletim do D.E.R. - 1943 - São Paulo.
7) Vargas, M. - "A escolha das cargas admissíveis para fundações de edifícios" Separata da Revista Acrópole - 1943 - São Paulo.
8) Nápoles Neto, A.D.F. - "Vibrações e trepidações dos solos" - Revista Politécnica no. 145 - 1944 - São Paulo.
9) Martins, H.A. - "Tensões transmitidas ao terreno por estacas" - Revista Politécnica no. 119 - 1945 - São Paulo.
10) Vargas, M. - "A exploração do subsolo para fins de estudos de fundações" Revista Politécnica no. 149 - 1946 - São Paulo
11) Vargas, M. e Bernardo, G. - "Nota para o Estudo Regional do Solo no centro da Cidade de São Paulo" - Revista Politécnica no.194 - 1946 - São Paulo
12) Aidar, T. - "Medidas de vibrações do solo produzidas pela cravação do Estacas Franki" - Revista Politécnica no. 149 - 1946 - São Paulo.

x) As defined by Mr. H.A. Mohr in his paper Exploration of Soil Conditions and Sampling Operations.

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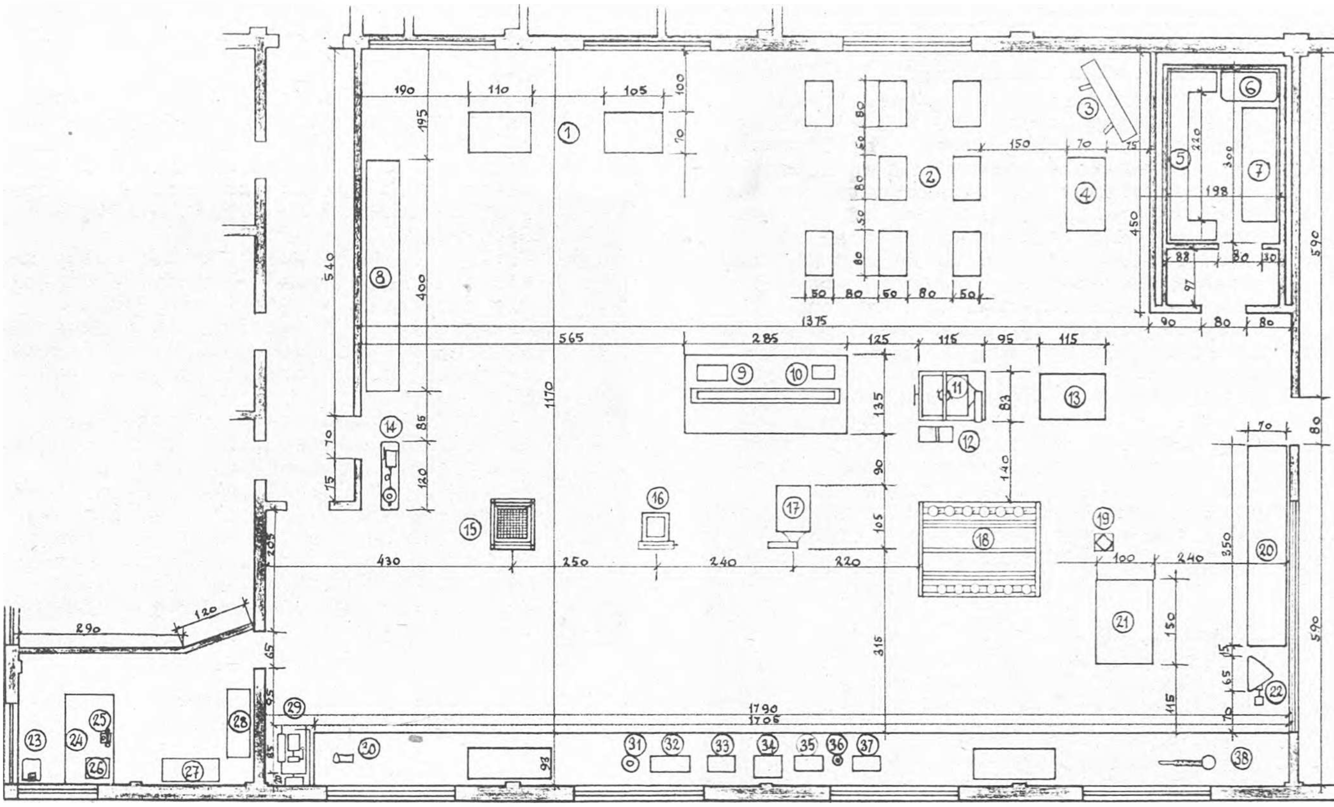
XII b 24 REPORT FROM SOIL MECHANICS LABORATORY OF "ESTACAS FRANKI LTDA" RIO DE JANEIRO - BRAZIL

A.J. COSTA NUNES

Engineer of "Estacas Franki Ltda" and Professor in "Escola Nacional de Engenharia"

1. The Laboratory of "Estacas Franki Ltda" is maintained by the Brazilian firm of the same name.
   Address: Rua do Equador no. 186 - Rio de Janeiro - Brazil
   Date of creation: March, 1942.
   The Laboratory is a Section of the Technical Division. It is related to the Projecting Section controlled by the same Division. The Technical Division is directed by a Superintendent and a staff controlling design and execution.
2. Purpose of the Laboratory :
   a) to furnish data for design of foundations and earth works in general (compaction, sand drains, injections etc):
   b) to control the execution and loading tests of foundations :
   c) to observe settlement of foundations and structures :
   d) to train engineers specialized in soils and foundations.

   In addition to this, the Laboratory handles other services such as : studies of concrete, agressivity of waters and soils, physical and chemical tests of materials, etc.
3. In charge of the Laboratory: Maria de Lourdes Campos Campello - C.E.
   Regular staff: 2 Civil Engineers
   2 Laboratory men
   2 Assistants
   Students : 8 Engineering students attend Soil Mechanics class at the Laboratory. Classes are in the care of Icarahy da Silveira C.E.
   Unskilled workmen for soil exploration do not belong to Laboratory staff.



LABORATORY OF ESTACAS FRANKI LTDA
RIO DE JANEIRO - BRAZIL - SCALE:- 1:50

Plan of Laboratory

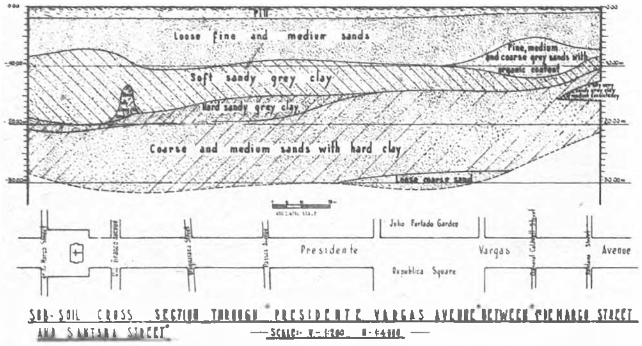
1 - Desks
2 - Desks for students use
3 - Blackboard
4 - Desks
5 - Shelves for storage of undisturbed soil samples
6 - Tank
7 - Sample preparation table
8 - Shelf for storage of tested samples
9 - Beam balance (0.1 g sensibility)
10 - Analytical balance
11 - Triaxial compression test apparatus
12 - Apparatus for permeability test
13 - Space reserved for direct shear apparatus (in construction)
14 - Hydraulic press
15 - Sieves for concrete aggregates
16 -
17 - Platform scales (1 ton capacity)
18 - Consolidation loading frame
19 - Compaction apparatus
20 - Shelf
21 - Plane-table
22 - Testing sieve shaker
23 - Telespeaker (Inter-office phone)
24 - Desk
25 - Telephone
26 - Steel file
27 -
28 - Shelves
29 - Compressor
30 - Scale (2 kg capacity)
31 - Desiccator
32 - Beam balance (0.1 g sensibility)
33 -
34 - Constant temperature drying ovens
35 - Vacuum Pump
36 - Mechanical mixer
37 - Scale (20 kg capacity)

FIG. 1

4. Equipment
The Laboratory occupies a floor area of 213 sq. meters, humid room and office included. A plan of Laboratory is given in fig. 1. The equipment consists of the apparatus for classification tests and determination of mechanical properties of soils: water content, specific gravity, grain size, Atterberg limits, permeability, consolidation (12 Casagrande oedometers), triaxial compression tests; apparatus for compaction tests, settlement measures, neutral pressure measures and devices for disturbed and undisturbed sampling of soils.

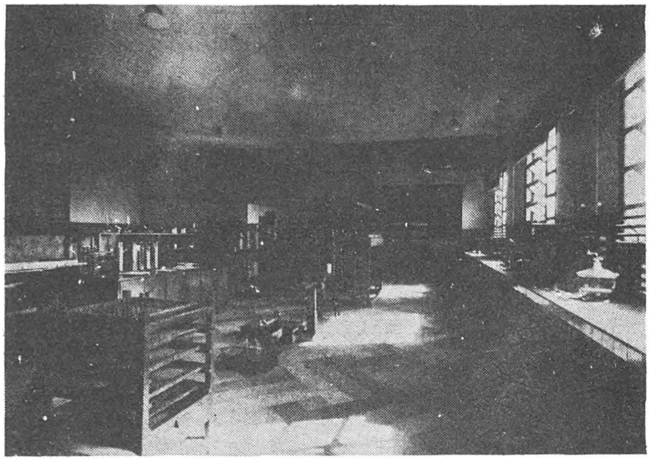
5. Types of soils in the working region:
Although located in Rio, the activities of the Laboratory extend throughout Brazil. There are, of course, numerous types of soil under investigation. A typical profile of "Presidente Vargas Avenue", in central part of Rio, is shown in fig. 2.

6. Most important practical investigations.
The Laboratory in collaboration with the Technical Division has studied, among many others, the foundations for "Police Building" in São Paulo city which will be one of the highest concrete buildings in the world; stability of the sheet piling bulk-



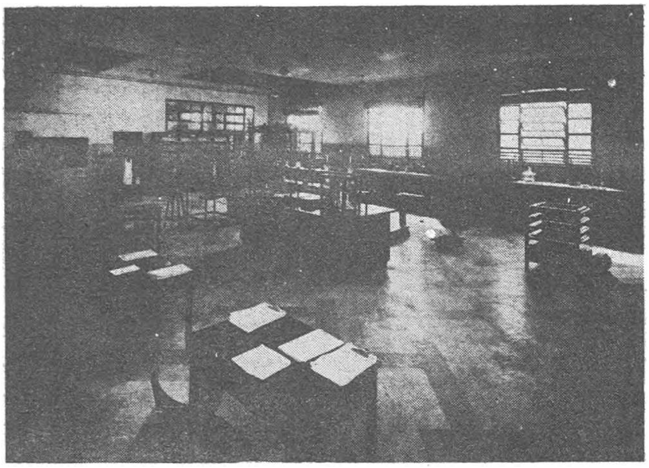
A typical profile of "Presidente Vargas Avenue"

FIG. 2



View of the Laboratory

FIG. 5

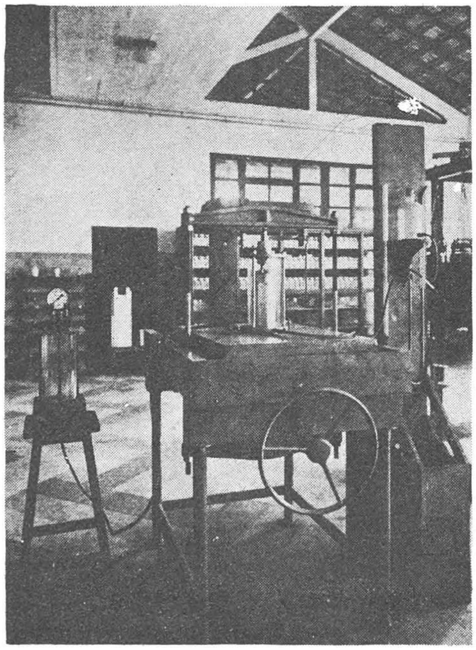


View of the Laboratory

FIG. 3

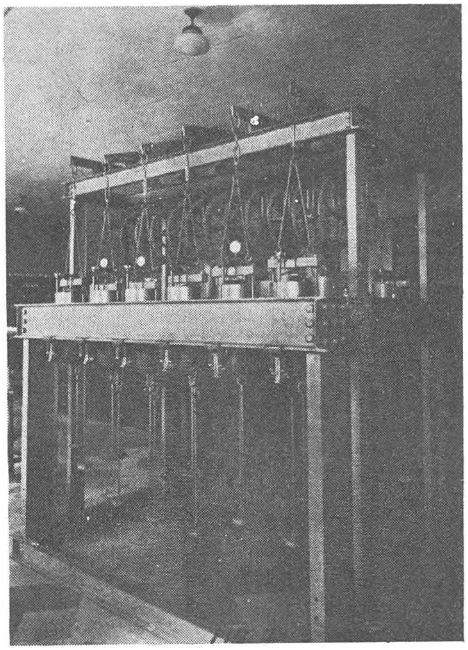
View of the Laboratory

FIG. 4



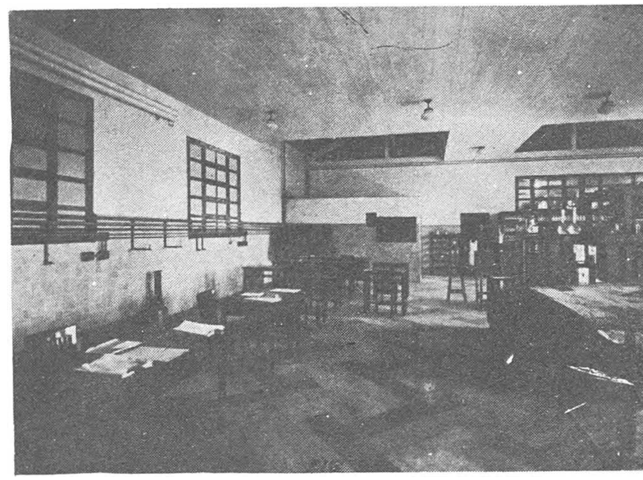
Laboratory - Triaxial loading machine-assembly

FIG. 6



Consolidation test apparatus

FIG. 7



View of the Laboratory showing the class room for Soil Mechanics course

FIG. 8

heads of Belém dry dock; the contribution of piles-cap bearing capacity to the bearing of pile foundations; the comparison between length of piles as estimated by geotechnical studies and the true length after the piles are driven; bar penetration tests and many other works not yet published. Theoretical-statistic studies in connection with loading distribution on groups of piles and regarding foundation codes were published.

7. Most important research in progress.
Neutral pressure variation in beds of clay with accelerated consolidation - by sand drains; estimate of length of piles based on soil sample tests ; effects of agressive waters and soils on foundations.

8) Published works
In collaboration with Technical Division lectures have been given and works about research, divulgation and teaching have been published, the more important of which are mentioned below.

View of the Laboratory and the regular staff at work

FIG. 9

REFERENCES

1) Ladvocat, Victor Marie - Earth pressures distribution according to M.G. Spangler - Revista Municipal de Engenharia - November 1941.
2) Silveira, Icarahy da - Rain fall characteristics of Rio de Janeiro - Revista Municipal de Engenharia - November 1941.
3) Silveira, Icarahy da - Drainage of Airports related to undersoil shear strength - Revista Municipal de Engenharia - November 1942.
4) Silveira, Icarahy da - Erosion and landslides in Rio de Janeiro - Revista Municipal de Engenharia October 1943.
5) Silveira, Icarahy da - Storm water drainage in pavements. Revista Municipal de Engenharia - April 1944.
6) Silveira, Icarahy da - Diametral compression tests in a soil cylinder - Revista Municipal de Engenharia - July and October 1944.
7) Silveira, Icarahy da - Considerations on the "Second Symposium on Soil Mechanics" - Rio de Janeiro 1947 "Concrete" no. 89
8) Costa Nunes, A.J. - Determination of the Bearing Capacity of a Pile Foundation - Revista Municipal de Engenharia - January 1943.
9) Costa Nunes, A.J. - Soil Mechanics and Civil Engineering. Revista Engenharia C.T.C.-1944
10) Costa Nunes, A.J. - Load Distribution on the piles of a pile-footing. Symposium de Estruturas Vol. 2 - July 1944.
11) Costa Nunes, A.J. - Design of pile foundations - Revista Politécnica - October 1945.
12) Costa Nunes, A.J. - The bearing value of spread foundations. Revista Engenharia CTC-no. 29 - September 1946.
13) Magalhães, Catullo P. - Elastic Stability of piles - Revista Politécnica no. 146 - 1943.

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XII b 25 REPORT ON THE DIVISION OF SOILS AND FOUNDATIONS OF THE "INSTITUTO TECHNOLÓGICO DO ESTADO DO RIO GRANDE DO SUL" (ITERS) - BRASIL

C.J. MUNARSKI,

Chief Engineer Division of Soils and Foundations
Technological Institute of Rio Grande do Sul - Brasil

The government of the State of Rio Grande do Sul - BRASIL created the Technological Institute in 1943, to develop activities in the testing and research fields. At the time the Institute absorbed the laboratories belonging to the State Highway Department and to the School of Engineering, at Porto Alegre.

The Highway Department laboratory initiated the soil studies in 1938. The purpose of that laboratory was the soil identification and its applications to the road problems. With the creation of the Instituto Technológico do Rio Grande do Sul (ITERS) the above orientation was maintained, but very soon it was found necessary to organize a special division for soil studies for engineering purposes, and in April 1943 the Soils and Foundations Division, as it is now, was created.

The boring, field and laboratory test equipments were then organized and staff was trained for different new activities.

The State of Rio Grande do Sul is rich in soil types, varying enormously in kind and quality. After nine years of cooperative study, the ITERS is able to select many reports of soil conditions. Our experience has shown that it is not sufficient for the soil technician to identify soil types in the field, to show their distribution in the maps and to determine their characteristics to management practice. These data are necessary but, in addition, they must be interpreted and assembled in such a way that they may be available to design engineers.

PERSONNEL

The personnel of the Soils and Foundations Division is under the supervision of the chief engineer CASEMIRO JOSE MUNARSKI

The field engineers are:

Mr. THEMIO PORTINHO VITA and
Mr. FLAVIO MENEGHETTI BORRALHO

and the laboratory engineer is:

Mr. ARTHUR WENTZ SCHNEIDER

The tests, field and laboratory, are made by six well trained laboratory men. The Division has also one clerk and one draftsman.

The boring personnel is composed of six foremen assisted by a variable number of workers, normally four men for each equipment.

ACTIVITIES

The study of soils in Rio Grande do Sul covered at first road and highway problems and involving later foundations for buildings and other structures. Actually, the main purpose of the Division is the study of foundation conditions for dams, building and bridges.

The research activities are applied to identification of decomposed granitic rocks for road surfacing and the investigation of sandstone for civil engineering purposes.

EQUIPMENT

The equipment of the Division is divided in two main classes, according the types of tests we run:

a) field tests and sampling
b) laboratory tests

The first class of equipment is subdivided as follows:

1) boring and sampling
2) loading test
3) field laboratory

The boring equipment is composed of:

one diamond core drill machine with hydraulic feed and independent wash pump. This machine is intended to recover 30 mm core in normal service and 20 mm in special case;

one shot drill machine to recover rock core with 38 mm diameter;

these above mentioned machines are provided with equipment to study the water infiltration in bed rocks;

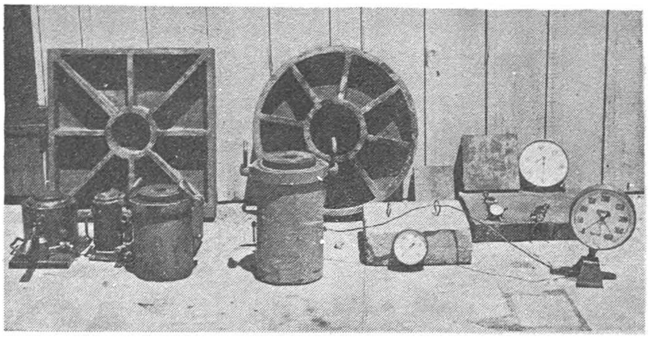
three manual boring equipments. This material is composed chiefly of a derrick with manual crane, 2½" drive pipes, rods, augers, samplers with slit in side, hammers and manual pump. It is intended for soil sampling operation, mainly for clay and silty soils;

one manual boring equipment, to recover undisturbed 12 cm diameter samples of soil.

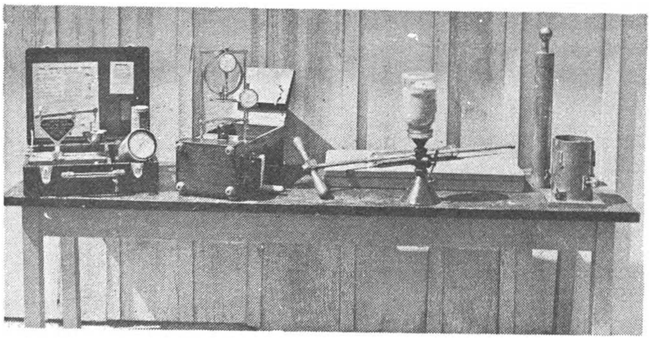
The loading test equipment consists of many iron plates of variable size, various hydraulic jacks and measurement devices (see Fig. 1).

The principal field laboratory test equipment is one speedy moisture tester, one unconfined compression apparatus, Proctor needles and density cones (see Fig. 2)

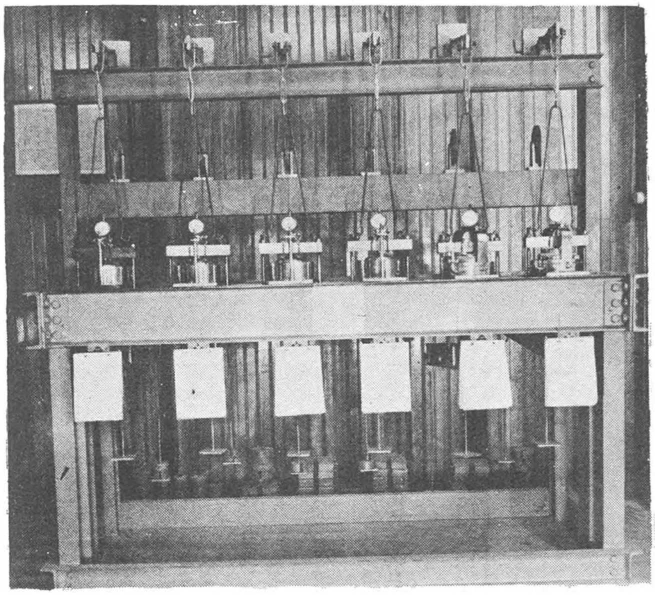
The main laboratory test equipment is in-



Loading test equipment.
FIG. 1

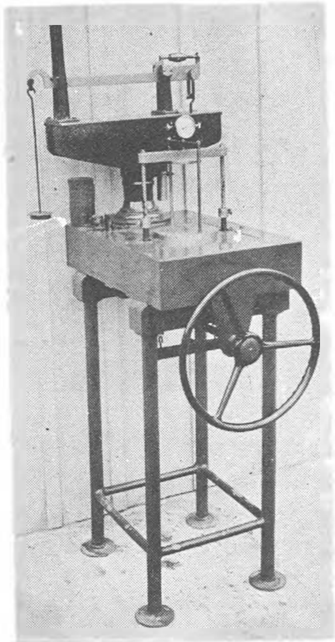


Field laboratory equipment.
FIG. 2



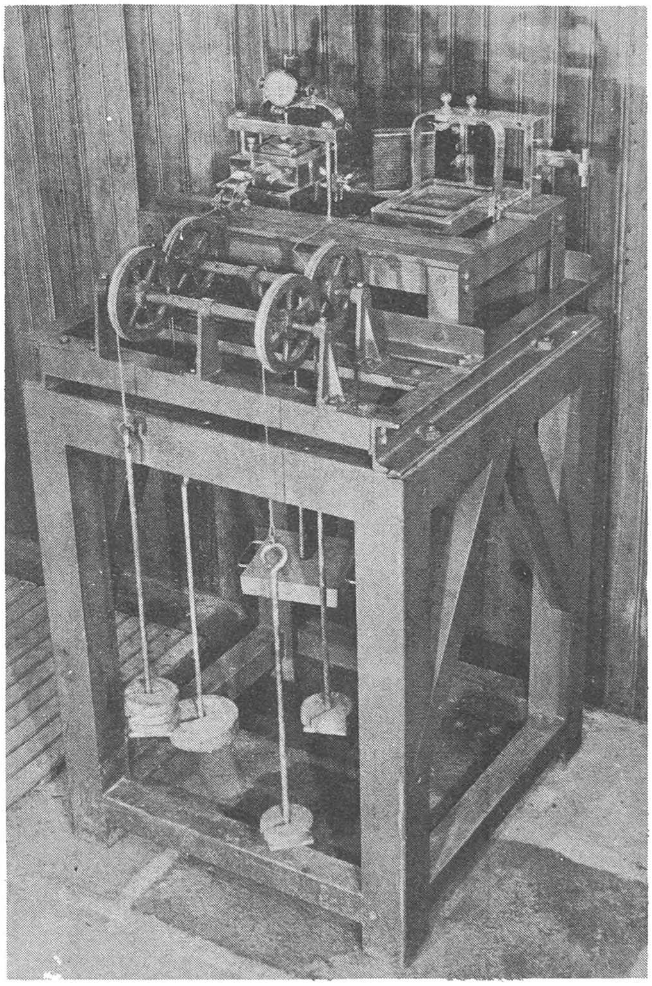
Consolidation apparatus

FIG. 3



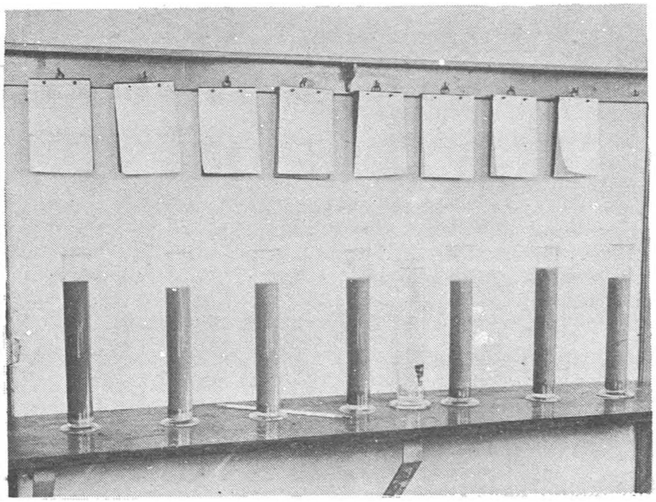
Unconfined compression apparatus

FIG. 5



Direct shear apparatus

FIG. 4



Hydrometer analysis

FIG. 6

stalled in Porto Alegre and consists of the following:

one consolidation apparatus with six "Casagrande" consolidation devices (see Fig. 3);

one direct shear apparatus, equipped with two shear boxes (see Fig. 4);

one unconfined compression test apparatus (see Fig. 5);

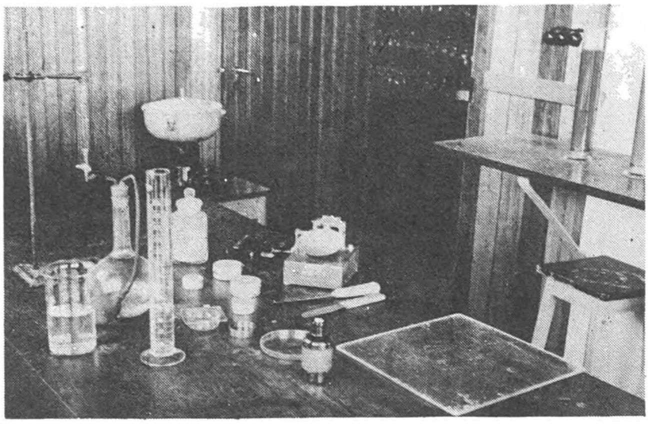
five permeameters, two of which are of constant head, two of falling head and one for horizontal capillarity;

equipment for hydrometer analysis (see Fig. 6);

equipment for Atterberg's limits (see Fig. 7);

equipment for standard Proctor test.

The laboratory has a moist chamber to secure



Atterberg's limit equipment.

FIG. 7

uniform quality of undisturbed samples and to prepare samples for physical test.

ACTIVITIES PERFORMED

The soil studies that have been made by this Division since its organization, cover:

1) Soil Stabilization

I - Soil cement. These tests follow the method described in technical papers of the Brasilian Portland Cement Association except for freezing and thawing durability tests.

II - Soil - lime - ashes mixture. These tests were applied to verify the influence of lime and ashes on the soil plasticity. They were conducted at various percentages of lime, ashes and lime-ashes combined.

III - Construction of short stabilized strips. Investigations were conducted in the field to develop a method for the design of the soil - lime - ashes stabilization. For that purpose some test sections were made 3 x 25 meters approximately. The information obtained from this job was very valuable. Other test strips were performed to establish the soil compaction specifications for earth dams embankments.

2) Airports

1 - Setting up a field laboratory for construction control of a military airfield at Santa Maria, in this State. For that service the following laboratory tests were made:

a) Proctor Standard on samples of borrow pits
b) Atterberg's limits
c) grain size distribution
d) natural moisture content
e) specific gravity on solid matter
f) field density by cone method
g) auger boring

II - Study of soil conditions for an apron and a runway at the military base of Gravatai.

a) Soil auger boring
b) Soil identification by grain size distribution, Atterberg's limits, natural moisture content and Proctor tests.
c) loading tests.

III - Soil identification for the airport at Bagé.

3) Dams.

Once created of the Special Commission for Irrigation services, the Institute was requested to study the foundation conditions and to make investigations of possible borrow pit areas to build 10 earth dams. The dams lengths range from 400 meters to 1,600 meters averaging the height of 20 meter. The studies of Tabatingaí, Capivarí, Iruilí, Duro and Divisa dams, all of them in Rio Grande do Sul, have already been concluded. Experiments on sand model for the study of seepage, through and under the mentioned earth dams, are being made by the Commission. The model tank was made of framework. It has a glass plate in one side to provide observation through the cross section of the model and in the other side were installed piezometric tubes for measurement of the pressure of infiltrating water. This study is only an indicative method from which very valuable information can be obtained.

4) Bridge and building foundations

The studies of subsurface conditions for bridge and building foundations are being divided in two main classes:

a) preliminary or general data
b) data to be used in final design for foundations.

In the preliminary study it is obtained a general idea of soil profile and rock depth. With this information it is possible to select the type of foundation. The final studies depend on the characteristics of the soil and selected foundation.

The preliminary studies are made by the Division of Soils using $2\frac{1}{2}$" manual dry sample boring equipment. The final are made by test pits and special equipment to recover undisturbed large samples. These samples should be representative of the natural conditions with the minimum of disturbance. For the final data are made laboratory and field loading tests.

This Division is being requested intensively for studies of highway, railroad and building foundations.

5) Roads

For the study of the influence of soil type on the design, construction and maintenance of roads, it is necessary to know some characteristics of soils on which the roads will be laid. These soil surveys are made before, during and after the construction of the road. The field services are made by auger boring and complemented by the laboratory tests.

Numbers of tests and studies made up to date by the Division of Soils and Foundations of the ITERS:

a) over 9000 meters of boring
b) tests on about 1900 soil samples
c) tests on about 750 rock samples
d) 52 loading tests
e) 10 soil cement studies
f) 4 soil - lime - ashes
g) 2 soil - ashes studies

Soil identifications were made by the methods approved by the "Associação Brasileira de Normas Tecnicas" (Brasilian Association of Technical Standards).

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XII b 26 SOIL MECHANICS LABORATORIES IN AUSTRALIA

A. Name and address of Institute.
Division of Soils, Council for Scientific and Industrial Research c/- Waite Institute, Private Mail Bag, Adelaide, South Australia.

Purpose: The Soil Physics and Mechanics Section of the Division of Soils is engaged on research into physical properties of soils and on soil surveys for engineering purposes.
The following lines are being followed:
Soil survey and foundation reports on soils of housing estates. Moisture and volume change in soils under house foundations.
Movement of water in soils and its retention.
Swelling of clays including X-ray examination.
Laboratory and field methods for defining texture and structure.

Name of staff personnel and specialists with indicated qualifications. In Soil Physics and Mechanics Section.
Marshall, T.J., M.Ag.Sc., Ph.D. Physical properties of soils.
In charge of Section.
Aitchison, G.D., B.E., A.M.I.E. (Augt.) Physical and engineering properties of the soil profile in relation to building foundations.
Norrish, K., M.Sc., X-ray examination of clays; swelling.
Stirk, G.B., B.Sc., Water entry and movement in soil.
Quirk, J.P., B.Ag.Sc. Soil structure.
Gurr, C.G., B.Sc. Soil moisture apparatus for use in field.

Number of Staff.
Division of Soils Staff number 43 of whom 9 are in the Soil Physics and Mechanics Section.

B. Departments with Laboratories engaged on testing and research in the field of earth dams and officers in charge.

MELBOURNE & METROPOLITAN BOARD OF WORKS,
110 Spencer Street,
Melbourne. Vic. .. D.F. Glynn - B.C.E.

STATE RIVERS AND WATER SUPPLY COMMISSION,
100 Exhibition St.
Melbourne. Vic. .. J. Mathews - B.C.E.
J.McN. Turnbull.

STATE ELECTRICITY COMMISSION OF VICTORIA,
22 William Str.
Melbourne. Vic. .. A. Rufenacht.

WATER CONSERVATION & IRRIGATION COMMISSION,
Sydney. N.S. Wales .. S.M. Munday - B.E. B.Sc.

C. Departments with Laboratories engaged in testing and research in the field of road and airfield pavement design and officers in charge.

COUNTRY ROADS BOARD,
Exhibition Buildings,
Carlton, Vic. .. A.H. Gawith. - M.C.E.
A.M. McPherson- B.Eng-Sc.

DEPARTMENT OF MAIN ROADS,
Castlereagh St.
Sydney. N.S. W. .. A.T. Britton- B.Sc. B.E.
N. West - B.Sc.

COMMONWEALTH DEPARTMENT OF WORKS & HOUSING,
271 Collins St.
Melbourne. Vic. .. H.T. Loxton - B.C.E. B.Sc.
M.D. McNicholl - B.Sc.

MAIN ROADS COMMISSION,
Brisbane.
Queensland .. E.G. Gurhrie - M.C.E. B.Sc. (Eng.)

DEPARTMENT OF HIGHWAYS AND LOCAL GOVERNMENT,
Currie St.
Adelaide. S.Aust. .. J.N. Yeates
G.F. Whillas - B.Sc.

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XII b 27 THE "LABORATORIO DE CAMINOS" OF THE "ESCUELA ESPECIAL DE INGENIEROS DE CAMINOS, CANALES Y PUERTOS", MADRID (SPAIN)

Mr. José Luis ESCARIO, Director

In the "Escuela Especial de Ingenieros de Caminos, Canales y Puertos" in Madrid (Spain), a laboratory on studies of Road Construction and Management is working since 1944.

Its name and address are:
LABORATORIO DE CAMINOS
Alfonso XII-3, MADRID (SPAIN)

It was mainly founded for research purposes but as the number of Soil Mechanics laboratories is yet very new in Spain, it has been necessary to work on other directions: the students of Engineering have made their practices of Soil Mechanics, and furthermore the Laboratory has answered many questions put on embankments, earth dams, stability of slopes, earth pressure on tunnel structures, soil stabilization, etc.

The names of the staff are as follows:
DIRECTOR:
Mr. José Luis Escario, C.E.
CHIEF OF THE SOIL MECHANIC DIVISION:
Mr. José A. Jimenez Salas, C.E.
CHIEF OF THE ROAD PAVEMENT DIVISION:
Mr. Antonio Lleó, C.E.
GENERAL CHEMICAL ASSISTANT:
Dr. Isidoro Asensio.

Aside from this staff, four laborers, a mechanic and a stenographer are permanently employed.

The Laboratory is equipped with the following apparatus employed for testing Soil Mechanics:

Nine compression devices with equipment for permeability measures.
Three Casagrande shearing machines.
Two triaxial compression machines.
A ring shearing apparatus.
An apparatus for unrestrained compressiom and tension test.
For the tension, the heads of the specimens are freezed with solid carbonic acid.
Three Casagrande apparatus for the determination of the liquid limit.
Equipments for the corn size analysis of soils, by the A.S.T.M. and International Robinson procedures.
A Enslin apparatus.
A capilarimeter.
Three permeameters for sand.
A metallic box with a glass wall for the study of the flow net.
Two Proctor molds and one Proctor needle.
A Swedish cone.
A Watts apparatus for stability tests of soil-asphalt mixtures.
An equipment for undisturbed sampling.
A field apparatus for loading tests.
A truck.
Three ovens.
A cold-storage plant for freezing tests.
Equipment for chemical analysis of soils.
A pH determination apparatus.
Two precision balances and a commercial one.
A 30 Ton compression testing machine.
Miscellaneous material.

The truck is going to be transformed into a traveling laboratory.

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XII b 28 THE "LABORATORIO CENTRAL DE ENSAYO DE MATERIALES DE CONSTRUCCTION"

a) Name and address of the Institute:
Soil Mechanics Section of the "Laboratorio Central de Ensayo de Materiales de Construcción" (Official Laboratory of the "Ministerio de Obras Públicas") Alfonso XII, 3, Madrid (Spain).

b) Objet:
Research and advisory institution for the problems of earth in connection with foundation engineering.

c) Name of staff personnel:
Manager: E. Torroja. M.A.S.C.E. - M. Royal Acad. of Sciences of Madrid. . Professor of the "Escuela de Ingenieros de Caminos, Canales y Puertos" of Madrid.

"Soil Mechanics" and "Structural Models"

Chief: C. Benito. Civil Engineer
A. Ferres. Assistant Engineer at "Soil Mechanics"
A. Moreno. Assistant Engineer at "Photoelastic Testing of Structural Models".

"Chemical section".

Chief: J. Coronas. Doctor in Chemical Sciences.

d) Number of personnel permanently employed:
Six workmen, a designer and administrative personnel. Thirty-three workmen in other Laboratory Sections.

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XII b 29 THE "INSTITUTO ESPANOL DE EDAFOLOGIA,ECOLOGIA Y FISIOLOGIA VEGETAL" OF THE "CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS"

Finality: This Institute is mainly devoted to the investigation.
Director: Prof. José M.ª Albareda Herrera
Vicedirector: Prof. Lorenzo Vilas López.
Secretary: Prof. Tomás Alvira Alvira.

Chiefs of the Sections:
Prof. Fernando Burriel (Chemical Analysis of Soils)
Prof. Vicente Aleixandre (Physico-chemistry of Soils)
Prof. Cruz Rodríguez Muñoz (Humus)
Prof. Lorenzo Vilas (Microbiology of Soils).
Mr. Luis Cavanillas. Agricultural Eng. (Lysimeters)
Mr. José A. Jiménez Salas, Civil Eng. (Physic of Soils).

Scientific collaborators:
Dr. Mariano Claver Aliod
Dra. Narcisa Martín Retortillo
Dr. Isidoro Asensio Amor
Dr. Manuel Muñoz Taboadela
Dr. Antonio Guerra Delgado
Mr. José García Vicente;
and 19 assistants.

This Institute has moreover two detached sections in the country, one of them in the South

in Granada, whose chiefs are:
Prof. Enrique Gutiérrez Ríos (Physicochemistry of Soils)
Prof. Ángel Hoyos de Castro (Chemical Analysis of Soils).

The other section radicates in the North, in Santiago de Compostela and the Chief of which is the Prof. Francisco Bellot Rodríguez.

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EXISTING INSTITUTIONS AND INDIVIDUALS WORKING ON SOIL MECHANICS IN INDIA

National Committee for India

The following institutions in India are interested in the theory and practice of Soil Mechanics, in the manner indicated against each:-

1. THE CENTRAL BOARD OF IRRIGATION:

The functions of this body are mainly coordination of research and development undertaken by institutions mentioned below. The Chief Engineers of the Public Works Departments (Irrigation and Hydro-electric Branches) of all administrations in India, Burma and Ceylon are members of this Board and the present Secretary to the Board is Shri N.D. Gulhati, I.S.E., M.I.E., (Ind.). The offices of the Board are at Kennedy House, Simlat S.W. All research and development relating, inter alia, to Soil Mechanics and Foundation Engineering carried out in the country is reported to and discussed at the annual meeting of the Board and its Research Committee. Recommendations are made to administrations concerned for the implementation of the decisions arrived at these meetings and programmes for future works are drawn out.

The Board has a permanent committee on developing, and modifying from time to time, standards for soil tests and related technique on which the principal engineering interests in the country are represented. The Board also maintains a technical library and an Information Bureau.

Lately the Board has organised a National Committee for India for the International Conference on Soil Mechanics and Foundation Engineering.

2. THE INDIAN ROADS CONGRESS:

The Indian Roads Congress is a body of engineers engaged or concerned directly or indirectly in the construction and maintenance of roads. The present secretary of the Congress is Shri H. Sunder Rao and the offices are at Jamnagar House, Shahjahan Road; New Delhi.

At the instance of the Indian Roads Congress, in 1937, the Government of India requested the Punjab Irrigation Research Institute at Lahore to investigate certain problems connected with Punjab Soils. The laboratory research work was not, however, correlated at the time with actual field tests. Recently field tests on a fairly extensive scale have been undertaken in the Punjab, and are being started in other parts of the country. The Indian Roads Congress has a Soil Research Sub-Committee to advise on soil research generally. This Committee has recommended a programma for experimental field tests on a very large scale. As a result, work on Soil Stabilization over 25 miles of roads in the Punjab, was taken in hand. This also provided training facilities for officers from other parts of India in the technique of soil mechanics and soil engineering as applied to roads. The details of work done in the Punjab have been described in a paper submitted to the International Conference by Shri S.R. Mehra, A.M.I.C.E., Superintending Engineer, East Punjab, who was in charge of the operations.

The Indian Roads Congress Sub-Committee's comprehensive scheme for a Central Soil Research Laboratory has also been accepted by the Government of India who propose shortly to establish a Road Research Institute at Delhi.

3. THE MILITARY SOILS ENGINEERING STATION:

The Military Soils Engineering Station is situated at Maithon, Post Office Chirkunda, District Manbhum in the province of Bihar. The officer incharge is Mr. A.K. Deb, M.Sc., who is assisted by four subdivisional officers (Technical) and a large subordinate staff.

The station is at present engaged primarily on soil investigations for earthen dams in the Damodar Valley and at Lalitpur in the United Provinces, but also undertakes work in connection with roads and air-fields.

4. THE CENTRAL WATERWAYS, IRRIGATION AND NAVIGATION COMMISSION:

Chairman - Shri A.N. Khesla, I.S.E., with offices at Curzon Road, New Delhi.

The Commission is interested in the subject of Soil Mechanics and Foundation Engineering in connection with schemes of regional development of the country as regards waterways, irrigation and navigation undertaken by it. The Soil Mechanics Laboratories of the Commission are being organised under the direction of Dr. R.C. Hoon, M.Sc., Ph.D.

5. THE FOREST RESEARCH INSTITUTE AND COLLEGE DEHRA DUN:

Apart from the work on specific soil problems in connection with the forests in India, the Institute interests itself with problems connected with Soil Stabilization under the direction of Dr. S. Krishna, Bio-Chemist in the Chemistry and Minor Forest Products Branch of the Institute.

6. CENTRAL STANDARD'S OFFICE - RAILWAY BOARD, NEW DELHI:

The Railway Board is organising a laboratory for experiments on soil pressure in railway embankments. The officer in charge is Shri V. Venkatramyya, B.A., B.Sc. (London) A.M.I.E.

7. SOIL STABILIZATION LABORATORY, PUBLIC WORKS DEPARTMENT, (BUILDINGS AND ROADS BRANCH) EAST PUNJAB.

The Laboratory, under the direction of Shri S.R. Mehra, A.M.I.C.E., Superintending Engineer and under the charge of Dr. H.L. Uppal, M.Sc., Ph.D., is situated at Karnal in East Punjab. The main functions of the laboratory are:-

(i) The training of engineering personnel from all parts of India in Soil Stabilization methods,
(ii) Research work on practical problems arising out of Soil Stabilization Construction, and
(iii) To advise on the suitability and methods of improvements of local soils for use in roads, buildings and air-fields.

8. Other Institutions:

Apart from the institutions described above, which are more or less of an All India character, there are many other laboratories or departments in India and Ceylon interested in the subject of soil mechanics and foundation engineering. The field of their activities is confined to administration boundaries, but the nature of the research undertaken by them is no less important.
These include:-

(i) Bengal - The River Research Institute, Anderson House, Alipore, Calcutta.
Director - Dr. N.K. Bose, M.Sc., Ph.D.
Officer incharge - Shri K.C. Niyogi, M.Sc.

(ii) Ceylon - Irrigation Research Laboratory, Jawatte Road, Colombo.
Director - Dr. R.V. Burns, B.Sc., Ph.D., D.I.C., A.M.I.C.E.
Officer incharge - Shri T. Mylavagam B.Sc., (Eng.) A.M.I.C.E.

(iii) Hyderabad - Engineering Research Laboratory.
Director - Dr. S.P. Raju, D. Ing. (Munich).
Officer Incharge - Sheikh Vadood Ahmad B.Sc., B.E.

(iv) Madras - Soil Mechanics Laboratory, Chepauk, Madras.
Officer incharge - Shri T.N. Seshadri, M.A.

(v) Punjab - Punjab Irrigation Research Institute, Lahore.
Director - Lt.Col. T. Blench, I.S.E.
Officer incharge - Dr. A.G. Asghar, M.Sc., Ph.D.

After the partition of the country from 15th August 1947, the Institution has been split to East Punjab and West Punjab Institutes. The latter remains at Lahore and the former is being set up at Amritsar in East Punjab under the direction of Shri S.L. Malhotra, I.S.E.

(vi) Irrigation Research Station, Hardwar (U.P.)
Director - Shri R.S. Chaturvedi, Executive Engineer.
Officer incharge - L.K. Mittal, B.Sc., (Hons.) C.E. (Hons.)

The (Buildings and Roads Branch) also has a full scale routine analysis laboratory at Lucknow.

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SOIL MECHANICS LABORATORY

Oostplantsoen 25, Delft, Holland

Director: Ir. T.K. Huizinga

Head of Research Department. Ir. E.C.W.A. Geuze

Head of Consulting Department: Ir. W.C. van Mierlo

INTRODUCTION

The Soil Mechanics Laboratory is a subsidiary of a foundation embracing both the Soil Mechanics and the Hydraulics Laboratory.

Although a close contact has been established between the Technical University of Delft and these Laboratories - persons connected with the laboratories are on the teaching staff of the University - they are not part of the University but are working under their own managements as independant units.

It is the twofold purpose of the Soil Mechanics Laboratory to carry out research work and to act as consultant on practical engineering problems.

The Research Department conducts special investigations, it puts theories to the test, it develops and improves methods of investigation, apparatus etc.

The activities of the Consulting Department of the Laboratory, concerned with practical problems, submitted by other agencies, are in fact the most extensive.

Since the establishment of the Laboratory in 1934 such a confidence in the science of soil mechanics has been inspired, that the demand for its services both in Holland and abroad has grown steadily. The increase of the number of orders received and the growth of the staff are evidenced by the diagrams shown in fig. 1.

To date a total of more than 2500 orders

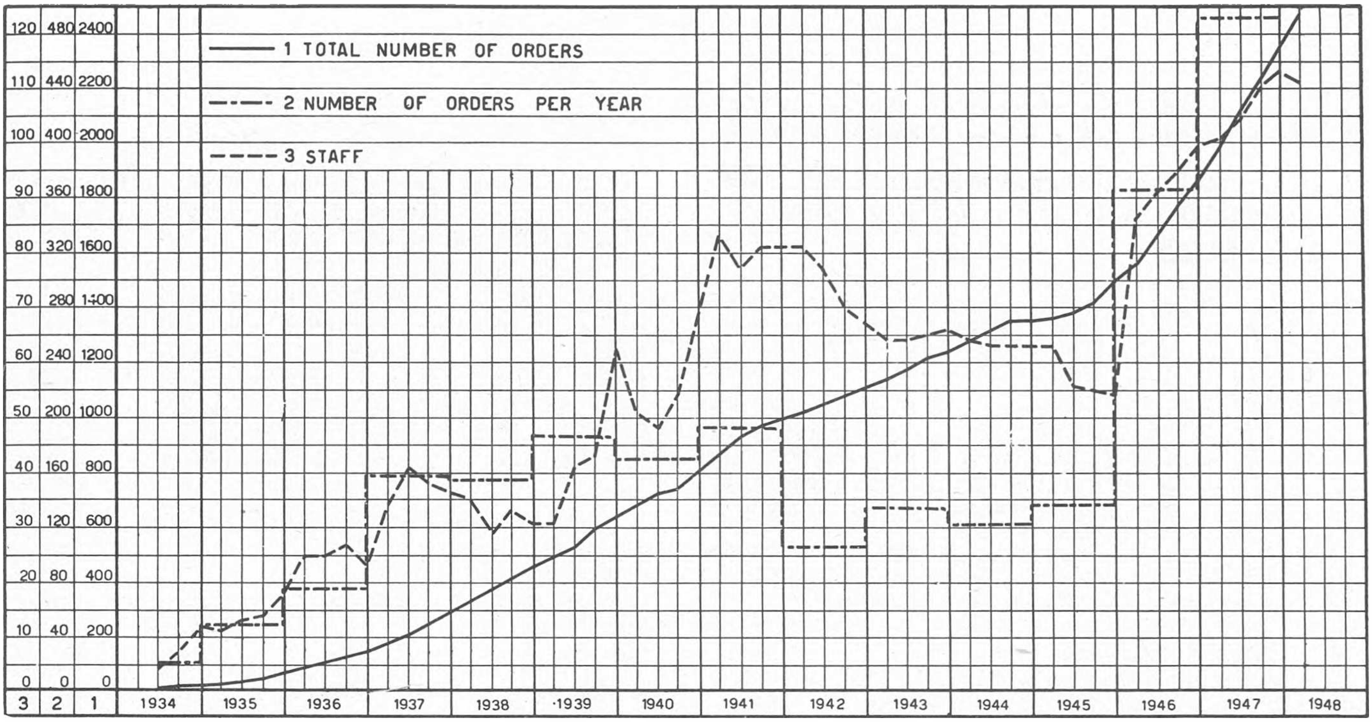

FIG. 1

have been accomplished, comprising a large variety of problems in the field of soil mechanics.

There has been a great demand for studies and investigations concerned with foundation problems: shallow foundations, pile foundations etc. At first this demand was mainly with respect to hydraulic structures, factories and other large buildings, but gradually also for dwelling-houses.

Advice is often sought on problems connected with the raising of the ground surface by earth fill, the design and the construction of dikes and embankments for roads and railways, reclamations etc.

Also for questions regarding the strength of sheet piles and the stability of retaining walls and slopes the Laboratory's facilities are repeatedly utilized.

Moreover, since the liberation, orders concerning the design, construction and improvement of airfields and runways have come in to such an extent, that it was decided to create a special subdivision of the consulting department.

The services of the Laboratory are not only sought by Government Departments, Provincial or Municipal, Railways and big companies, but also and in the first place by many private civil engineers, contractors and architects. The majority of these orders concern projects in the Netherlands, but a number of investigations are conducted for works abroad e.g. France, England, Venezuela, Persia, Curaçao, Suriname, Java, Borneo, New Guinea, Portugal, Trinidad, Egypt, Belgium, Argentina etc. For the execution of the orders the Soil Mechanics Laboratory can dispose of an organization composed of the following units:

1. An engineers' section of about 15 engineers, each in charge of the orders that have been especially allocated to him. To this end they can utilize the services of the sections mentioned below. They collect the resulting data and draw up a report to the client based on these data.
2. A field section comprising a staff of 50 men; it carries out the field investigations and is to that end equipped with the required apparatus, their own means of transport and a workshop. Its work consists mainly in performing soundings, both with the medium and with the heavy type of sounding device, in making borings, in placing pore-water pressure meters and in taking disturbed and undisturbed soil samples.
3. A laboratory, where soil samples are examined and tested. A special section of the laboratory is devoted to research.
4. A drawing office with a dozen draughtsmen, who work out the results of the under 2) and 3) mentioned operations.
5. A documentation section, comprising record-room and library; one of its purposes is to find and collect all documents of interest for the Laboratory, whether published at home or abroad.
6. An administration and a typists' office.

Fig. 2 shows the plan of the laboratory as it was in June 1948. The numbers 23-30 belong to the research section.

The building space for director, engineers, draughtsmen, documentation, administration and workshop amount to about 500 m².

FIELD INVESTIGATIONS. 1)

1. Soundings, to determine at various depths below a certain point on the surface the ultimate bearing capacity of the soil beyond which failure by shear occurs. Medium heavy soundings are made for general investigation, shallow foundations etc.; deepsoundings are made to determine the length and bearing capacity of piles.
2. Boring and soil sampling.
3. Pore-water pressure measurements.

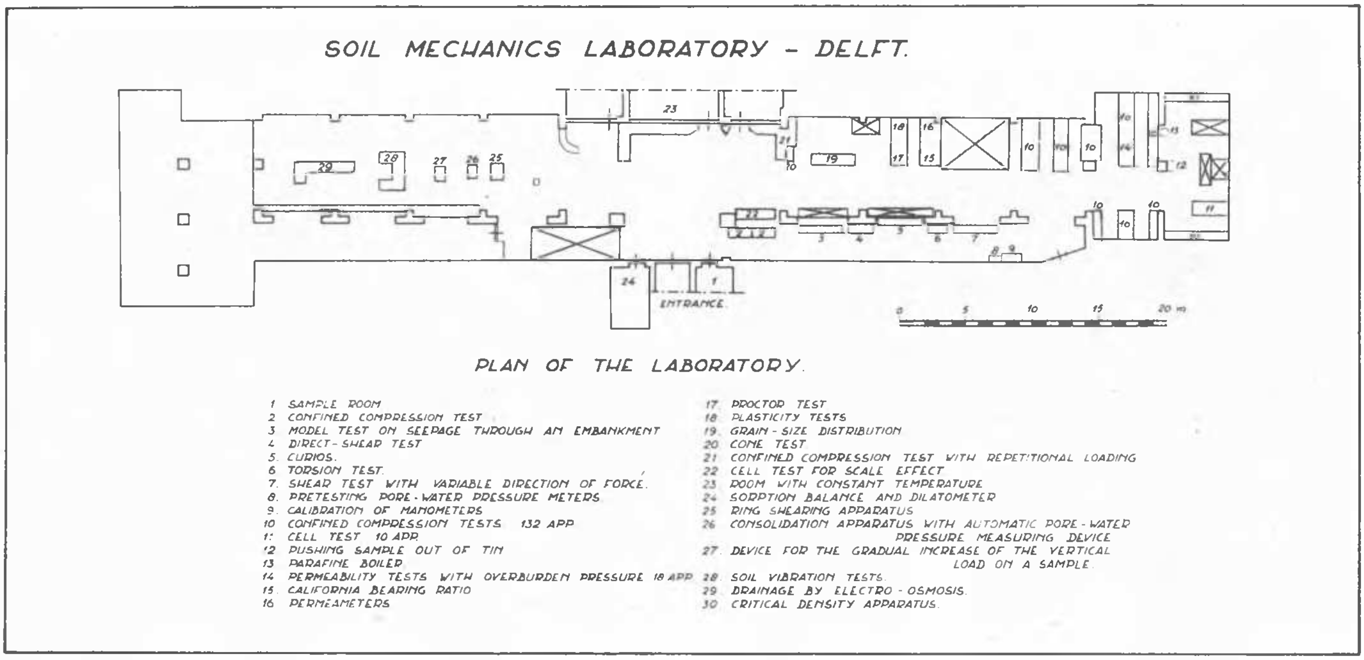

FIG. 2

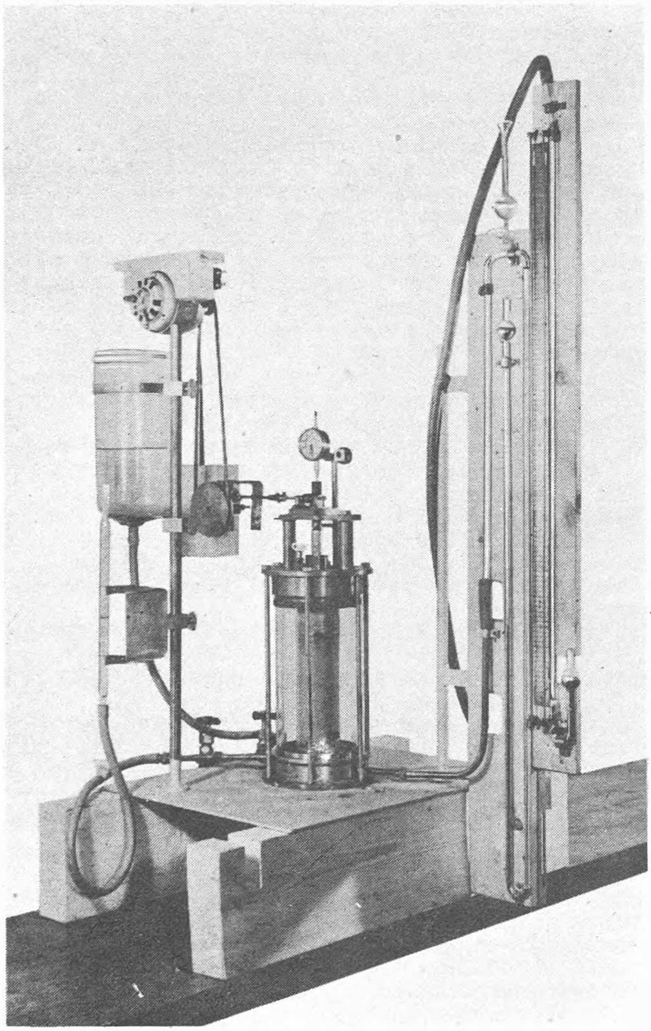

FIG. 3

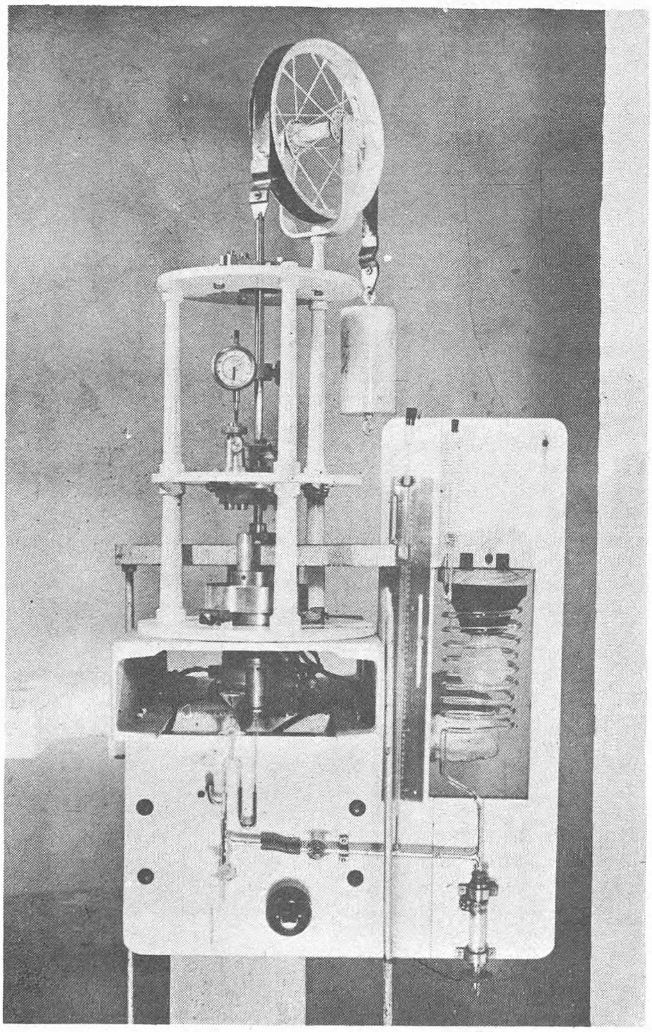

FIG. 4

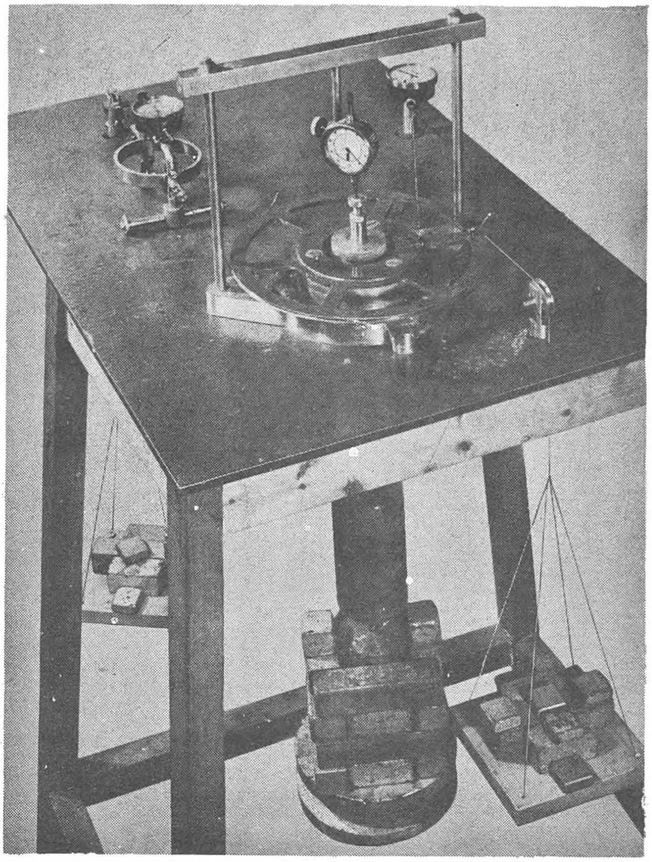

FIG. 5

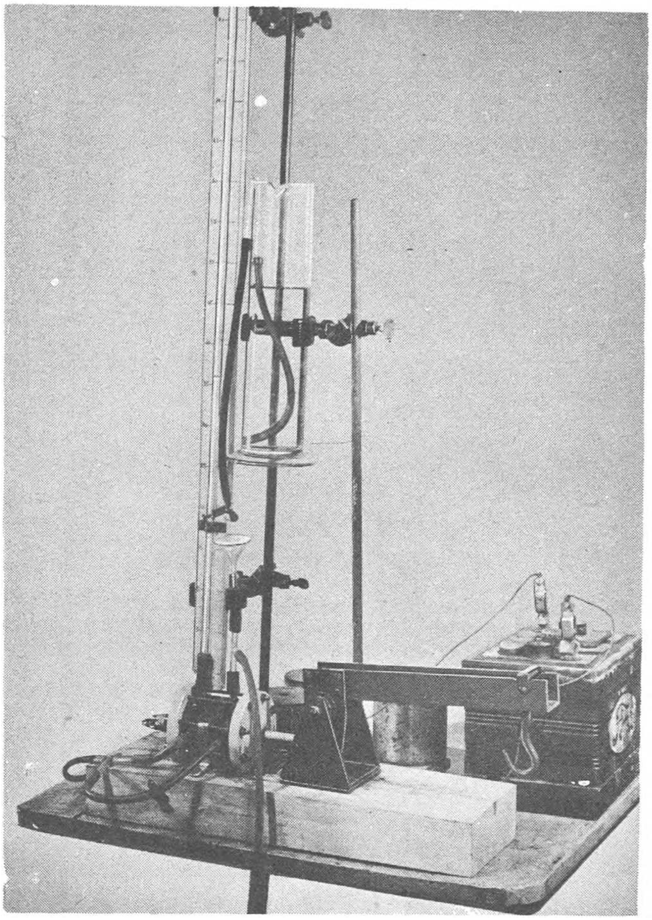

FIG. 6

COMMON INVESTIGATIONS IN THE LABORATORY. 2)

A. Identification tests for the determination of:
   1. Grain-size distribution, by means of sieves and by elutriation.
   2. Density, specific gravity.
   3. Water content, air content.
   4. Liquid limit, plastic limit, plasticity index, colour changing point, shrinkage limit, stickey point.
   5. Permeability of sands and cohesive soils.
   6. Capillary rise.

B. Tests for the determination of the mechanical properties.
   1. Conetest with or without overburden pressure.
   2. Confined compression test.
   3. Cell test.
   4. Proctor test.
   5. California Bearing Ratio.

INVESTIGATIONS CONDUCTED IN THE RESEARCH DEPARTMENT. 3)

Of many incidental investigations we mention:

1. Investigations into the changes of the density of sands at various ratios of principal stresses up to the limit of internal equilibrium (critical density) fig. 3.
2. The determination of the duration of the hydrodynamical period by means of the measurement of pore-water pressure fig. 4.
3. Tests in the ring-shear-apparatus, where the rate of sliding at constant shear force or the shearing at constant rate of sliding may be determined fig. 5.
4. To examine the suitability of a soil for the application of the method of electrical drainage use is made of a modified version of the apparatus of Schaad - Haefeli fig. 6.
5. Vibration tests in the field and in the laboratory, a.o. to determine the depth of layers with different strengths. fig. 7.

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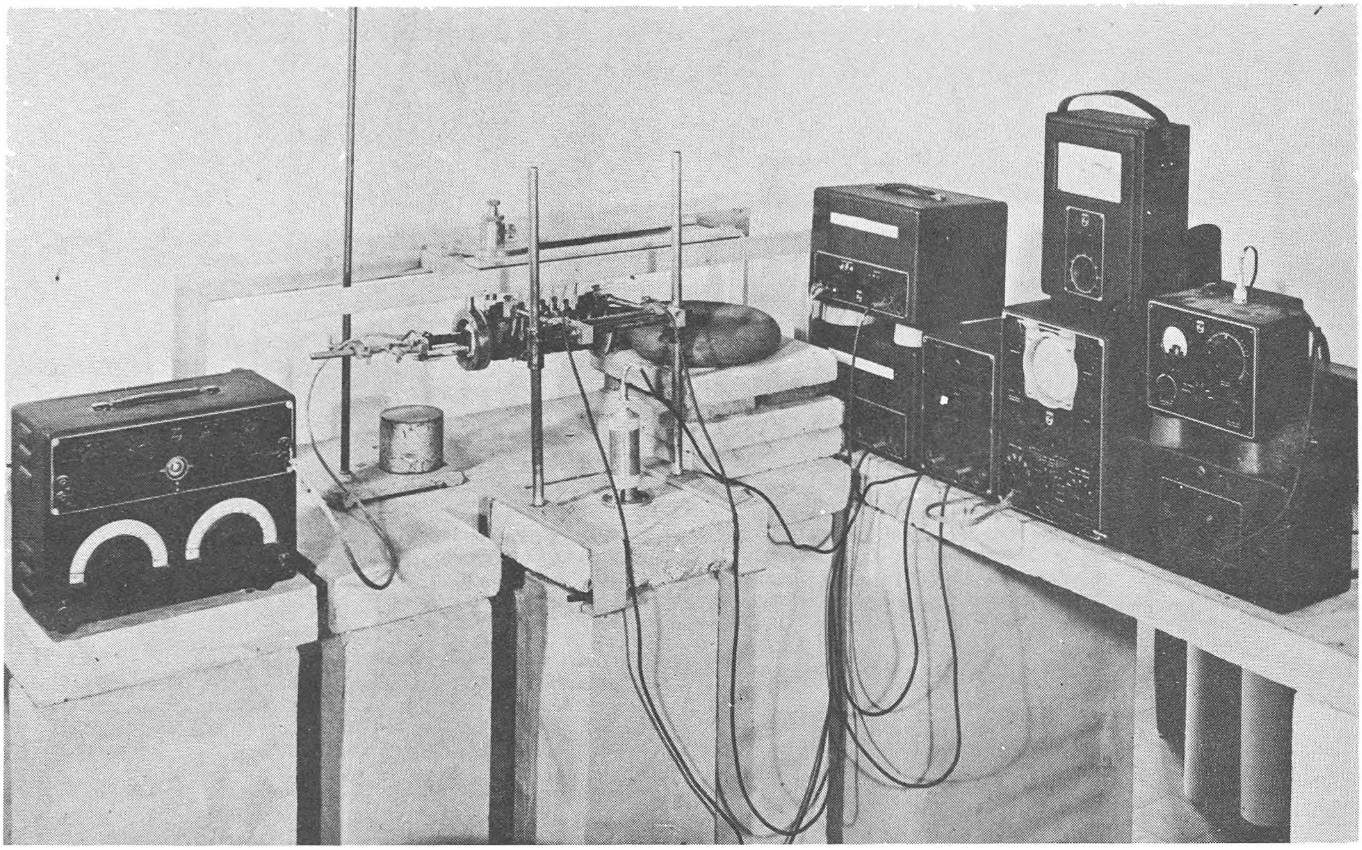

FIG. 7

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THE ACTIVITIES OF THE AMERICAN SOCIETY FOR TESTING MATERIALS IN SOIL TESTING AND RESEARCH

E.J. KILCAWLEY

Professor; Head of Division of Soil Mechanics and Sanitary Engineering
Rensselaer Polytechnic Institute, Troy, N.Y. - Member U.S.
Committee on Soil Mechanics

W.S. HOUSEL

Associate Professor of Civil Engineering, University of Michigan,
Ann Arbor, Michigan, - Research Consultant, Michigan State Highway Department.-
Member, U.S. Committee on Soil Mechanics

Through the work of the American Society for Testing Materials, a national technical society incorporated in the United States, but with a world-wide membership and prestige, there have been issued many test methods for evaluating the various properties of soils used for engineering purposes, and numerous publications that are of great interest and value to those concerned with this field. This work is carried out through the activities of a technical committee, Committee D-18 on Soils for Engineering Purposes, which includes in its membership many of America's leading experts in soil mechanics. In order to give those who will be attending the Second International Conference and those who may read this paper in the Proceedings, a broad picture of how the A.S.T.M. operates, a few details of the scope and activities are given here, followed by a more detailed description of the work of Committee D-18, in which the Society's activities in the field of soils is concentrated.

The American Society for Testing Materials, widely known as "A.S.T.M.", has a membership of some 6500 individuals, companies and other classifications who are concerned with the field of engineering materials. The Society has for its purposes "the promotion of knowledge of the materials of engineering, and the standardization of specifications and the methods of testing," and it concentrates its work specifically on these objectives.

It will be of interest to all of you to know that this Society, now almost fifty years old, had its roots in an international organization. Actually, from 1898 to 1902, - when the Society was formally incorporated, - it existed as the American Section of the International Association for Testing Materials that had been organized on the Continent. Annual meetings of A.S.T.M., however, are numbered from 1898, and in June 1947 the Society held its Fiftieth Annual Meeting at Atlantic City.

The Society carries on its work through the activities of over 70 technical committees which are responsible for the development of standard specifications and tests and keeping them up to date, and also to aid in research. The Society's work is advanced by the presentation and subsequent publication of technical data in the form of papers, reports and discussions.

MEMBERSHIP

Membership in the Society is open to those interested in its purpose and work and may be held by individuals, companies, corporations, associations, laboratories, governmental departments, technical schools and libraries. There are no professional requirements.

The membership includes Consumers of raw, finished or semi-finished products; Producers of materials; and a General Interest group. The latter group consists of engineers, scientists, educators, testing experts, research workers, etc., from all sections of the United States, as well as Canada, England, many Latin American and other foreign countries. The most important industries of the country are represented by membership. The Society is, in turn, represented in the activities of may national societies and of special groups which may be sponsored as joint activities of several societies having a common or special interest in the specific material or testing procedure.

WORK OF THE SOCIETY.

Since the first standards were issued in about 1900, the Society through its technical committees has worked rigorously to develop specifications and tests for materials, which would be authoritative and acceptable, and the world-wide use of A.S.T.M. standards is indicative of the care with which they are promulgated and issued. There are now over 1400 specifications and tests aggregating some 7000 pages. The Society's time-tested policy is one of rigorous examination, debate and ballot in technically qualified committees and before the Society, and especially of having the principal interests concerned, namely, consumers, producers, and general scientific interests, agree on the necessary requirements. As developments and advances take place, standard requirements are revised.

All specifications and test methods approved by the Society are normally published first as tentative, for a year, whereupon they are subject to review by the technical committee having jurisdiction for the purpose of adoption as standard with or without revision or for continuation as tentative.

The Society issues several primary publications which inclued: (a) The A.S.T.M. Book of Standards, published triennially, with its yearly Supplements, gives all the A.S.T.M. specifications and tests, except the methods of chemical analysis of metals, comprising well over 1400 tentatives and standards. (b) The Book of A.S.T.M. Methods of Chemical Analysis of Metals contains all of the analytical procedures for ferrous and non ferrous metals including spectrochemical and photometric methods. (c) The Proceedings contain the technical papers with discussions and the reports of the technical committees of the Society. It is published annually with special volumes of Indices issued covering five-year periods. (d) The A.S.T.M. Bulletin is a quasi-technical periodical issued 6 times yearly, and contains news of current activities of the Society and its committees, information on other standardization and research work, as well as a number of technical articles.

Numerous special compilations are published consisting of two types: (1) Standards pertaining to particular fields and, (2) symposiums, collections of technical papers and manuals of procedure covering certain fields. All A.S.T.M. tentatives and standards are printed in separate pamphlet form.

THE SOCIETY'S WORK IN SOIL MECHANICS.

The Society's original work in soil mechanics was initiated in 1933 by a Subcommittee on Soils for Highway Purposes under the technical committee D-4 on Road and Paving Materials. The work of this committee resulted in the acceptance and publication of nine tentative standards for soil tests. These appear in Part I, Vol. 35, of the Proceedings for 1935.

In 1936 the establishment of a new standing committee, D-18 on Soils for Engineering Purposes was authorized. The committee was organized in November of that year and eleven subcommittees appointed to carry out a program to consider nomenclature and definitions; to establish methods for sampling; to evaluate physical characteristics; to study compressibility; shear resistance; mechanical stability; bearing capacity; drainage; the bearing capacity of piles and the testing of stabilized soils.

Because of the continued and extended interest of Committee D-4 in soils for highway purposes, a joint subcommittee consisting of members of Committee D-4, and D-18 was soon established. Before a proposed specification, method of test, or procedure involving the use of soil as a road or paving material, is recommended for approval by the Society to the Administrative committee on Standards, it must have the approval of both committees as a whole by a two-third favorable vote.

It has been the established policy of Committee D-18 to limit its activities to the preparation of soil testing procedure and to avoid encroaching upon the field of engineering design which may be more appropriately undertaken by other professional engineering societies or organizations. This policy is set forth in a statement of the scope of activities of Committee D-18 as follows--

"To establish methods of sampling and methods of testing soils for engineering purposes, to consider the use of test results in specifications, to select acceptable nomenclature and definitions, and to promote research activity in the general field of properties and behavior of soils for engineering purposes.

It will be the policy of this committee to avoid, insofar as it is possible, dealing with methods of design of engineering structures and all those features of general practice in the use of soil as an engineering material which may not comprise methods of sampling and testing. It will, however, be considered within the scope of the committee's work to promote by every desirable means the close cooperation of other organizations and committees whose field of endeavor is closely allied to that of soil testing."

The Subcommittee on Nomenclature and Definitions has cooperated with the American Society of Civil Engineers, Highway Research Board, American Association of State Highway Officials, and other national Societies. This work culminated in the acceptance of the Tentative Definition of Terms and Symbols Relating to Soil Mechanics, A.S.T.M. Designation D653-42T, which appears in Part II. 1946 Book of Standards.

The extensive work on physical characteristics resulted in a modification of some of the original methods and the addition of other accepted methods of tests. These appear in the above mentioned volume under the designations of D420-45T, and D421-39T to D427-39T and D854-45T and D698-42T.

An extensive study of the shearing properties of both cohesive and noncohesive soils was carried out in several cooperating laboratories. This was the topic of a symposium held at the Annual Meeting in 1939. Results of this work are given by Professor F.J. Converse in Paper No. 5.11 of this Conference. For reasons readily understandable the committee has not written standard methods of tests to evaluate mechanical properties. Recommended procedures are, however, given in the Society's special publication: "Procedures in Soil Testing."

In cooperation with other interested groups, extensive investigation and experiment has been carried out on the study of stabilized soils with particular reference to soil-cement tests and bituminous mixtures. Certain standards have been accepted and appear in the above mentioned volume of A.S.T.M. standards. Many additional and alternate procedures and methods are however, now under consideration and discussion in this subcommittee and in the Joint D-4, D-18 subcommittee.

This committee wishes to emphasize that it welcomes criticism of any recommended standard procedure. Any criticism or recommended alternate or suggested extended procedure addressed to the Chairman will be placed in the hands of the particular subcommittee having jurisdiction. This information is invaluable as an aid in preparing procedures which will have a wide acceptance among the various groups dealing with soil and its use for engineering purposes.

In preparation for a Symposium on Soil Testing Methods, the committee, in 1941, started the collection of the descriptions of methods being used and recommended procedures in the categories of indicator and strength tests of soils and tests for soil-cement and soil-bituminous mixtures. The Symposium was held during the Annual Meeting in 1943. A compilation of these recommended test procedures, together with those already standardized by the Society were published in the compilation entitled "Procedures in Soil Testing" in September 1944. This book has had a wide distribution and is at present being reprinted to satisfy the demand.

The loss of personnel to the armed forces, the lack of transportation and hotel facilities and the need for activity on problems of more immediate necessity reduced committee activity to a minimum during the war years. During this time, however, serious consideration was given to a possible reorganization of the committee to meet the more challenging problems and the ever broadening aspects of soils testing in the post-war years.

This study resulted in a plan which was accepted by the committee and became operative in June 1947. The plan authorizes the establishment of five administrative subcommittees to assist the Chairman, and the appointment of research and standards subcommittees.

Four of the five administrative subcommittees provide for the editing of research reports and standards; the development of procedures for the evaluation of data, the use of statistical methods of research in the field of soil mechanics and the evaluation of data presented in research papers and reports. The soliciting of special papers and the preparations for symposiums on specific subjects. The fifth is a standing subcommittee on nomenclature and definitions.

The Society does not finance research work from its general funds. It does have an Administrative Committee on Research whose function is to consider means by which the work of the Society, in promoting knowledge of engineering materials, may best be advanced; and to encourage and stimulate investigations for this purpose under the auspices of the Society. It is both the intention and the practice for the technical committees in general to provide the means for financing their research projects through interested members of the industry or field.

The research subcommittees (designated by the letter R as shown below) are divided into subgroups or sections in order that the requirements of the major fields interested in the engineering use of soil, namely, the fields of highways and airports; foundations, and earthworks may be fully considered. The principal task of the corresponding standards subcommittee is the preparation of recommended procedures and standards based upon data accumulated by the research subcommittees.

The Chairman of each research subcommittee acts to coordinate the efforts of the sections. The sectional chairmen act as leaders of the sectional groups. The officers and members of the Executive subcommittee for the 1946 to 1948 term, and the Chairmen of the Research Subcommittees are given in the following tabulation:

OFFICERS

CHAIRMAN - - - - - - -	Professor E.J. Kilcawley Rensselaer Polytechnic Institute, Troy, N.Y.
1st VICE CHAIRMAN - -	Professor W.S. Housel, University of Michigan, Ann Arbor, Michigan.
2nd VICE CHAIRMAN - -	Professor F.J. Converse, California Institute of Technology, Pasadena, California.
SECRETARY - - - - - - -	Mr. R.F. Blanks U.S. Bureau of Reclamation, Denver, Colorado.
ASSISTANT SECRETARY - -	Mr. W.G. Holtz, U.S. Bureau of Reclamation, Denver, Colorado.

MEMBERS

Professor D.M. Burmister, Columbia University, New York, N.Y.	Mr. M.D. Catton, Manager, Soil Cement Bureau, Portland Cement Association, Chicago, 10, Illinois.
Professor K.B. Woods, Purdue University, Lafayette, Indiana.	Mr. H.F. Clemmer Engineer of Materials 208 Bryant Street, N.W. Washington, 1, D.C.

RESEARCH SUBCOMMITTEES

	Name and Division	Chairman
R-1	SURFACE AND SUBSURFACE EXPLORATION Sections on Geological, Geophysical & Pedological Aspects. Aerial Mapping of Soils.	Professor K.B. Woods, Purdue University, Lafayette, Indiana.
R-2	SOIL INVESTIGATION AND SAMPLING Sections on Subgrades, Foundations and Embankment Materials.	Mr. C.W. Allen Acting Chief Engineer, Ohio State Dept. of Highways Ohio State University. Campus Columbus, 10, Ohio.
R-3	PHYSICAL CHARACTERISTICS OF SOIL Sections on Grain Size, Density, Atterberg Limits, etc.	Mr. Harold Allen, Principal Materials Engineer, Public Roads Administration Federal Works Building Washington, 25, D.C.
R-4	PHYSICAL PROPERTIES OF SOILS Sections on Capillarity and Permeability.	Mr. E.F. Bennett, Principal Soils Engineer, New York State Dept.Public Works Alf. E. Smith State Office Bldg. Albany, 1, N.Y.
R-5	STRUCTURAL PROPERTIES OF SOIL Sections on Consolidation, Direct Shear and Triaxial	Professor D.M. Burmister, Columbia University, New York, N.Y.
R-6	PHYSICO-CHEMICAL PROPERTIES OF SOIL	Mr. E.F. Preece, Office of District Engineer, U.S. Corps of Engineers, First and Douglas Sts., N.W. Washington, 25, D.C.
R-7	IDENTIFICATION AND CLASSIFICATION OF SOILS Sections on study of Geological, Pedological, Classification; Areal Photographs and Identification and Classification for use in Highways, Foundations and Earth Works.	Mr. George W. McAlpin, New York State Dept. Public Works Alf. E. Smith State Office Bldg. Albany 1, New York.
R-8	SPECIAL AND CONSTRUCTION CONTROL TESTS Sections for Study of Subgrade and Base Courses, Earth Dams and Embankments and Stabilization with various Admixtures.	Mr. H.F. Clemmer, Engineer of Materials, 208 Bryant Street, N.W., Washington, 1, D.C.
R-9	DYNAMIC PROPERTIES OF SOIL	Professor R.K. Bernhard, Rutgers University, New Brunswick, N.J.
R-10	BEARING CAPACITY TEST OF SOIL IN PLACE Sections for study of Load and Pile Bearing	Mr. L.A. Palmer, Bureau of Yards and Docks, Navy Department, Washington, D.C.

At the June 1947 Annual Meeting, the Symposium subcommittee, under the Chairmanship of W.S. Housel, presented a Symposium on Load Tests of Bearing Capacity of Soils, consisting of 6 papers, as follows:

"Field Loading Tests for the Evaluation of the Wheel Load Capacities of Airport Pavements"
by L.A. Palmer, Navy Department.

"Methods of Testing Soils for Runways and Foundations"
by Elwyn E. Seelye, W.D. Bailey and S.D. Teetor, of Seeyle, Stevenson and Value, Consulting Engineers.

"The Use of Load Tests in the Design of

Flexible Pavements"
by W.H. Campen and J.R. Smith, Omaha Testing Laboratories.

"Field Bearing Tests Applied to Pavement Design"
by Robert R. Philippe, War Department, Corps of Engineers.

"A Cyclic Load-Test Procedure"
by Jean E. Hittle and W.H. Goetz, Joint Highway Research Project, Purdue University

"A Canadian Investigation of Load Testing Applied to Pavement Design"
by Norman McLeod, Department of Transport, Ottawa, Canada.

These papers, together with the discussions, will be reprinted and may be obtained for a nominal fee by addressing the Society Headquarters, 1916 Race Street, Philadelphia, 3, Pa. At the same meeting, the Special Papers subcommittee, under the Chairmanship of Mr. M.D. Catton, presented the following papers of special interest. These papers, together with discussions may be found in the Proceedings.

"The Use of the Maximum Principal Stress Ratio as the Failure Criterion in Evaluating Triaxial Shear Tests on Earth Materials"
by W.G. Holtz, U.S. Bureau of Reclamation.

"Uplift Pressure on Bridge Foundations in Clay Revealed by Shear Tests"
by G.O. Kerkhoff and W.F. Housel, Michigan State Highway Department.

"Tests for Thermal Diffusivity of Granular Materials"
by William L. Shannon and Winthrop A. Wells, Harvard University.

The 1947-48 Special Papers subcommittee, under the Chairmanship of Mr. C.W. Allen, is now preparing for the presentation of six papers of special interest at the next Annual Meeting of the Society in June 1948. It is planned to reprint these two groups of papers in a special publication which will be ready for distribution as soon as possible after the Annual Meeting.

A special subcommittee is, at this writing, being considered to expand and bring up to date the pamphlet, "Procedures in Soil Testing". Under this plan, the committee hopes to gather, arrange, and publish information which will be acceptable as a guide to aid in the classification of soil and in the valuation of its characteristics and properties essential for its most efficient use in all branches of engineering practice.

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SOIL ENGINEERING AT PRINCETON UNIVERSITY

Gregory P. TSCHEBOTARIOFF

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SUMMARY

The paper sketches the development of Soil Engineering work at Princeton and the present integration of its different phases both in teaching and in research. An outline is given of the methods and procedures of undergraduate and graduate instruction of Civil Engineering students in the theory and in the practice of Soil Mechanics. Soil Physics, Soil Chemistry and Engineering Geology and in their correlated application to problems of exploration, design and construction in civil engineering work. The main research problems under investigation are briefly discussed.

I. TEACHING

The development of Soil Engineering work at Princeton was gradual. The present methods and scope of instruction are outlined in the following description of the separate courses now given.

A. Foundations, Soil Mechanics and Earth Structures.

This was the first Soil Engineering course at Princeton. It was introduced in 1937 as an undergraduate fourth year course on Foundations which included instruction in the theory of Soil Mechanics and in its laboratory practice. It was recognized that every civil engineer has to deal at some time or other with engineering problems which cannot be rationally solved or even approached without some knowledge of Soil Mechanics. The aim of the course was to provide graduating engineers with such necessary elementary knowledge as would enable them to handle simple cases, to discern difficulties which would require the assistance of an expert, to appreciate the limitations of the present knowledge in this field and to understand publications dealing with further developments in it. In its present form the course consists of three one-hour lectures and one three-hour laboratory period per week during one fifteen week term. The course is based on the principle that soil testing and the theory of Soil Mechanics should not be taught separately from their applications. It outlines the following subject matter:

1) Soil Formation, Soil Mechanics Terminology and Basic Formulae.

2) Consistency Limits, Moisture-Density Relationships and Methods of Soil Compaction.
3) Capillarity of Soils, Frost Heaving and its Prevention.
4) Permeability and Compressibility of Soils.
5) Stress Distribution in Soils and Settlement Analysis.
6) Shearing Strength of Soils, Stability of Slopes and Bearing Capacity of Foundations.
7) Lateral Earth Pressures.
8) Exploration, Sampling, Soil Identification and Classification.
8) Water Seepage and Quicksand Phenomena.
10) Applications of Soil Mechanics to the Design and to the Construction of:
    a) Mat, pile and caisson foundations of buildings and bridges.
    b) Retaining walls and sheet pile bulkheads.
    c) Earth dams, embankments and canals.
    d) Highway and airport basecourses.

B. Foundation, Soil Mechanics and Earth Structure Problems.

This course was introduced in 1942 as a graduate fifth year course and formed a direct continuation of the undergraduate fourth year course of similar name outlined above. The fifth year course consists of two-one hour lectures and two three-hour laboraotry periods per week during one fifteen week term. Instruction is given by the "case" method. Students are required to perform the laboratory tests and the computations necessary for stability and settlement analyses of specific cases illustrating various types of civil engineering structures. The includes problems of gravitational flow of water and flow-net construction. Selected articles and publications are assigned for study and are discussed in class.

C. Soil Stabilization.

This graduate fifth year course was introduced in 1943 when Dr. Winterkorn joined the Princeton Faculty. It consists of two one-hour lectures and one three-hour laboratory period per week during one fifteen week term. About one-half of the available time and effort is devoted to fundamental relationships and basic facts, and the other half to present-day applications. A list of the subject matter treated is as follows:

Basic

1) Weathering of igneous rock, transportation, classification and metamorphosis of the reaction products as influencing soil-parent material.
2) Soil formation as a function of parent material, topography and climate.
3) Critical analysis of fundamental genetic and engineering use classification.
4) Soil-water relationships as function of the amount and surface-chemical character of the internal soil surface including consideration of the clay minerals, the silicasesquioxide ratio, the exchangeable ions, and the physical condition of water under high adsorption pressures.
5) Soil temperature relationships: progression of daily and seasonal temperature waves and effect of temperature on the physical state of soil-water; variation of water-adsorptive forces in a soil with temperature fluctuation and effect on the bearing power of the soil.
6) Normal and abnormal soil-physiology; movement of water in viscous, film and vapor flow under gravitational, adsorption, capillary, and thermic potentials; accumulation of water underneath pavements; frost-heave phenomena; electric drainage, and electrochemical hardening, microbial activity.

Applied

7) Purpose, action mechanism and classification of stabilization methods.
8) The physical mechanism of compaction and densification.
9) Principles and practice of:
    a) granular soil stabilization;
    b) soil-bitumen design and construction;
    c) soil-cement design and construction;
    d) soil-resin design and construction;
10) Electric soil treatment.
11) Miscellaneous and newest developments.

D. Engineering Geology.

The course is given by Dr. W.T. Thom, Jr., on a combination seminar and conference basis with 3 contact hours per week during one 15 week term. It deals with:

1) The nature, form and origin of different kinds of rock and soil masses.
2) The original and the induced structural features characterizing rock and soil masses.
3) The geologic problems likely to be met in tunnelling; dam construction; highway, building and foundation work.
4) The geologic interpretation of topographic, areal, structural and geophysical maps and of airplane photographs.

E. General Instruction.

Graduate students specializing in Soil Engineering work are required to take all the special Geological Engineering courses listed above, but are not allowed to limit their studies to that branch only. It is attempted to give them a broader preparation for the future by requiring them to take additional advanced courses in the general fields of Administration, Structural and Highway Engineering, Theory of Elasticity and Chemistry and Physics. The detailed selection of courses is adapted to the interests and to the needs of each individual student.

Seminars attended by graduate students and by research personnel of both laboratories are sometimes arranged for the discussion of controversial topics.

F. Thesis

A thesis, which is required of all candidates for an advanced degree is usually selected by a man studying Soil Engineering in one of the fields in which research is being done. The special equipment available and used for the purpose is listed in the report giving "Data on U.S. Laboratories, Personnel, Equipment and Testing Techniques" submitted to this conference by the U.S. National Committee on Soil Mechanics.

II. RESEARCH

The special fields in which soil engineering research is now conducted at Princeton are as follows:

G. Research of the Soil Mechanics Laboratory.

Since its organization in 1937 by Gregory P. Tschebotarioff, the Soil Mechanics Laboratory has aimed at the improved application of laboratory soil test results to the design and to the construction of Foundations and of Earth Structures. The following studies have been emphasized:

1) The results of laboratory consolidation and shearing strength tests have been occasion-

ally checked by and correlated to the observed performance of full-scale structures in the field.

2) The application of electric resistivity SR-4 strain gages to model tests has been initiated and developed. Studies are continued for the purpose of perfecting their use over long periods of time to permit strain readings on elements of full-scale foundations and bulkheads.

3) A study of lateral earth pressures of granular and of cohesive soils is underway both by means of large-scale model tests on flexible bulkheads and by using a special high pressure laboratory device, the "Lateral Pressure Meter".

4) A research study undertaken for the U.S. Civil Aeronautics Administration dealt with the effects of vibrations on the bearing properties of soils and was completed in 1946. Other soil-vibration studies, such as investigations of resonance problems of machinery foundations, are being continued.

5) Tri-dimensional model gelatine studies of soil deformations produced by various types of construction operations have been experimented with.

H. Research of the Soil Physics Laboratory.

The Soil Physics Laboratory was organized for the Civil Engineering Department in mid-summer 1943 by Hans F. Winterkorn who continued in it the Soil Stabilization Studies for the U.S. Civil Aeronautics Administration, started a year earlier at the University of Missouri; these were completed in 1946.

The laboratory has set as its goal the development of truly "low-cost construction and maintenance" roads. This involves:

1) Determination of the best possible use of local soil and also of locally available granular materials and of actually or potentially available cementing and (or) waterproofing agents.

2) Knowledge of the micro-climatic factors which tend to break down soil stability, and therefore affect useful life and maintenance costs of the road.

The approach is both fundamental and practical, and is indicated by the list of items treated in the soil stabilization course. The scope of study and application is world-wide, originating from war necessities and continued for peaceful purposes in cooperation with U.S., and with foreign governmental agencies. Research and instruction of foreign students is directed toward a solution of their own domestic problems which often are at great variance with those obtaining in the U.S.

Close cooperation with respect to domestic and foreign fields is maintained with the American Road Builders Association and with the Highway Research Board.

I. Cooperative Research Projects.

Cooperative research carried out jointly by both laboratories includes:

1) Study of the nature of the structural strength of some naturally deposited clays. 2)

2) Study of the performance of stabilized soils in the presence of vibratory and of slow repetitional loading. 3)

3) Study of the effects of electro-osmosis on the lateral earth pressures of consolidating clay backfills.

Several papers submitted for publication by the 2nd. International Conference on Soil Mechanics and Foundation Engineering describe the results of part of the above research and provide further references.

The support provided to the development of the above teaching and research program by Professor Elmer K. Timby, Chairman of the Department of Civil Engineering and by Professor Kenneth H. Condit, Dean of the School of Engineering, is hereby acknowledged.

CONCLUSIONS

Successful Soil Engineering work requires knowledge of a large number of auxiliary sciences and arts. Furthermore, the field is so wide and the employed concepts and methodologies so variant, that specialization becomes a practical and economic necessity, so far as the applied phases of soil engineering are concerned.

This practically necessary specialization must, however, not be permitted to result in a hermetic separation between the several fields and their exponents. Rather, by cooperative efforts, covering borderline cases, windows must be left open which permit the specialist to maintain a general perspective of the whole field, although his own research and teaching must, of necessity, be confined to his own department.

With respect to instruction, it is felt that this should make available to the student the accumulated specialist knowledge of experts who should help the student to combine by means of his own mental effort the presented parts into a general picture.

REFERENCES

1) "Undergraduate Instruction in Soil Mechanics as Part of a Course on Foundations" by G.P. Tschebotarioff, Proceedings, Purdue Conference on Soil Mechanics and its Applications, 1940.

2) "Sensitivity of Clay to Remolding and its Possible Causes" by Hans F. Winterkorn and Gregory P. Tschebotarioff, Proceedings Highway Research Board, 1947.

3) "Testing of Submerged Bitumen-Sand Mixtures by Slow Repetitional Loading" by Gregory P. Tschebotarioff and Hans F. Winterkorn, Proceedings Highway Research Board, 1947.

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XII b 34 TESTING EQUIPMENT AND RESEARCH ACTIVITIES OF THE SOIL MECHANICS LABORATORY NORTHWESTERN UNIVERSITY

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INTRODUCTION

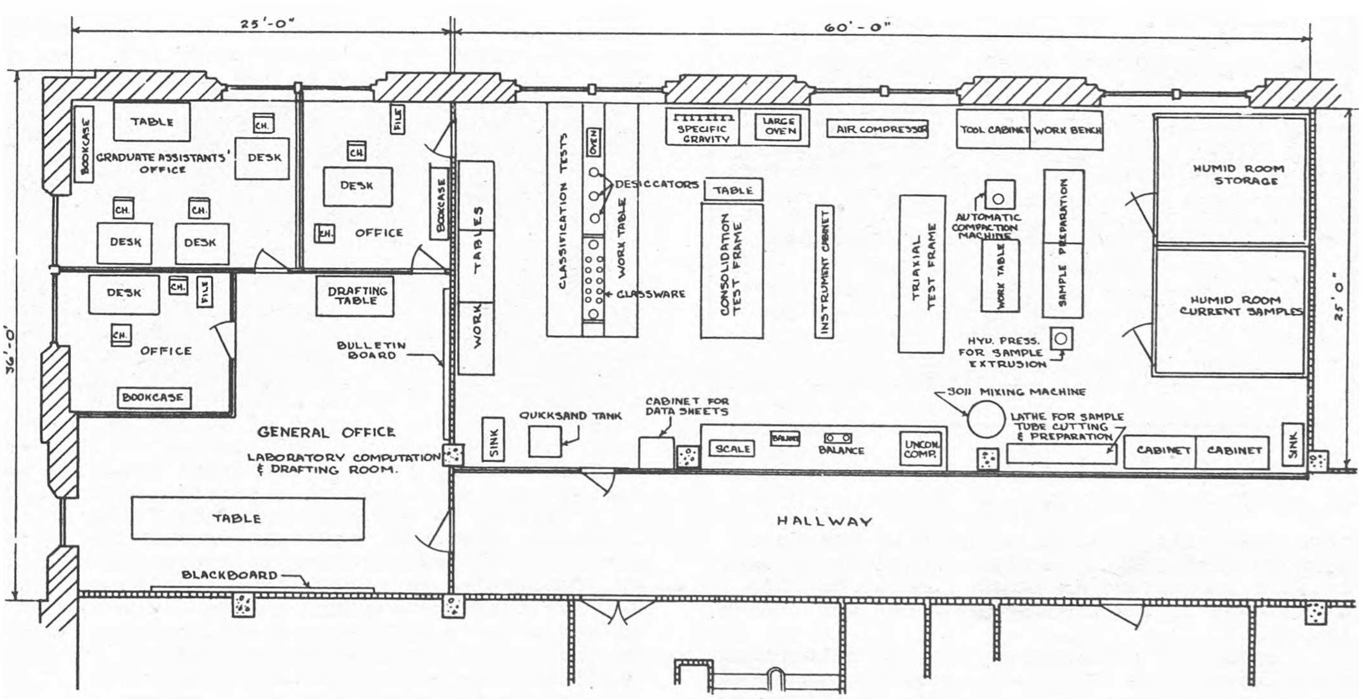
The Soil Mechanics Laboratory at Northwestern University is designed for three uses -- undergraduate teaching, graduate teaching, and research. Although the character of ach of the uses differs markedly from that of the others, the laboratory is laid out as a single unit. This is desirable both from a teaching and an operational viewpoint. Activity in graduate work and research, carried on in the same laboratory as undergraduate teaching, stimulates the interest and curiosity of the undergraduate, and introduces him to the more advanced phases of the subject. The majority of undergraduates taking laboratory instruction may never perform some of the more involved tests and research. Nevertheless they become aware of their existence and conscious of the practicality and limitations of various methods. It is the policy of this laboratory to encourage students, both graduate and undergraduate, to observe activities in the laboratory and if they feel so inclined or have ideas of their own, to make use of laboratory facilities to satisfy their curiosity. From an operational viewpoint, a laboratory contained in a single unit has many advantages, since the functions overlap and duplication of equipment is avoided.

A plan of the laboratory is shown in fig. 1. The laboratory may be divided into four parts, reading from left to right: offices and conference room space; routine tests; consolidation and triaxial testing; compaction, soil preparation and storage. The convenience of having a complete laboratory all in one large area cannot be overemphasized. A description of the equipment and the research activities carried on with this equipment follows.

CONSOLIDATION TEST EQUIPMENT

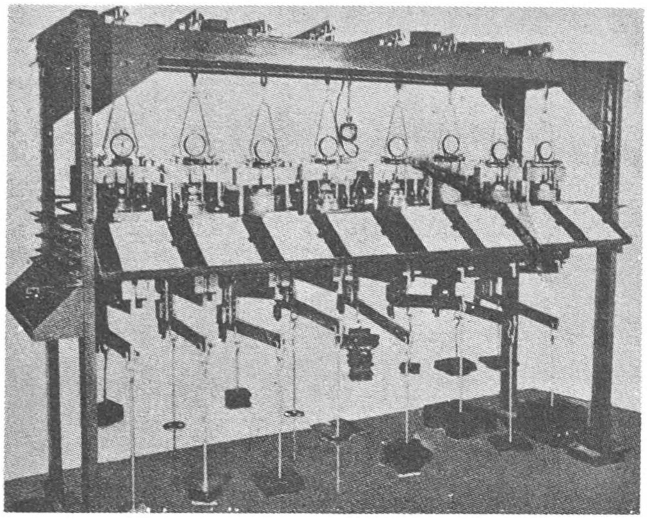
Consolidation tests are loaded on a test frame capable of holding eight tests simultaneously (fig. 2). Loads are applied by means of a multiple lever system. The mechanical advantage of the system using the long hanger is 40 to 1, and using the short hanger is 10 to 1. By starting with a 1 kg weight on the short hanger, the load may be doubled for each increment by using only three different units of weights, 1 kg, 4 kg, and 16 kg. The loading schedule is shown in fig. 3. Routine tests are carried to a load of 2560 kg. The consolidation test frame and lever system is, however, designed for a maximum load of 5000 kg on a sample 100 sq. cm in cross-section. Loads are applied to the specimen by means of a loading yoke, which is counterbalanced. The dead weight of the lever system is also counterbalanced, so that when adjusted and no dead loads are placed on the hangers, a small displacement of the lower lever will cause it to oscillate freely with little damping.

Consolidation test rings of both floating and fixed types are 100 sq. cm in cross sectional area and 3/4, 1¼, and 1½ inches in thickness. For research purposes, a number of much thinner rings and rings of smaller area



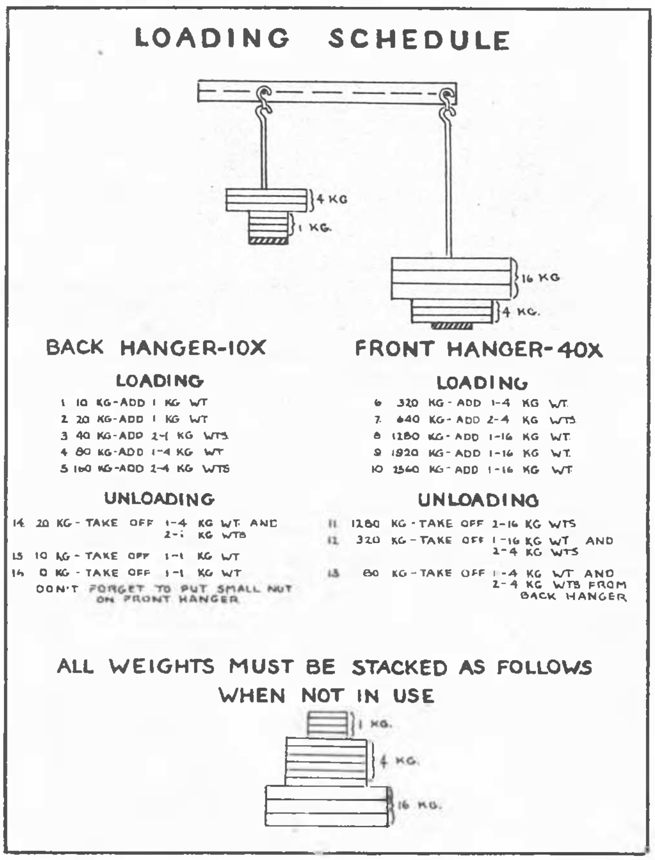
Plan of Soil Mechanics Laboratory

FIG. 1



Consolidation Test Frame

FIG. 2

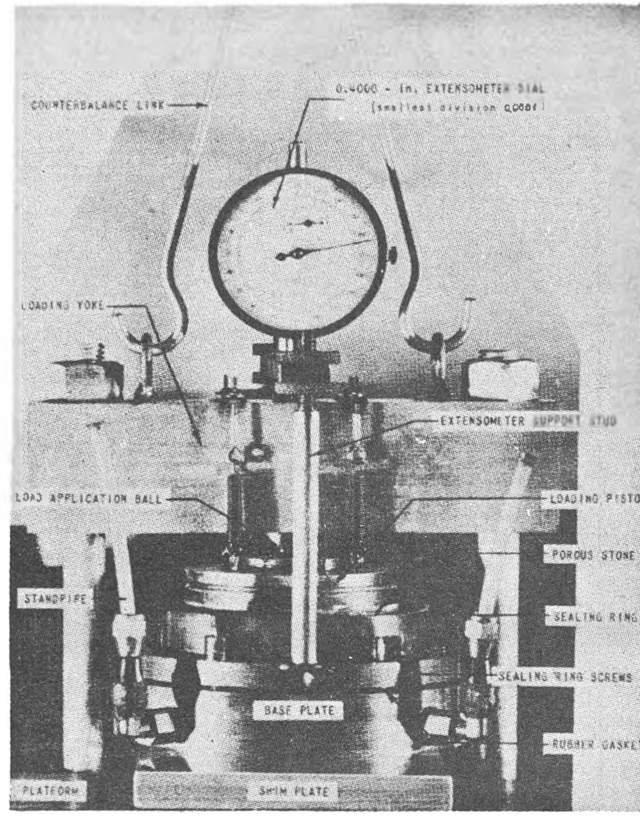


Loading Schedule for Consolidation Tests

FIG. 3

have been used. A modified form of the Casagrande fixed ring type consolidometer as used in this laboratory is shown in fig. 4. This is a close-up of one of the eight devices shown in fig. 2.

Among the research activities concerning consolidation is a project recently completed to determine the effect of specimen thickness on consolidation test results. Specimens of five thicknesses of the same soil were tested.

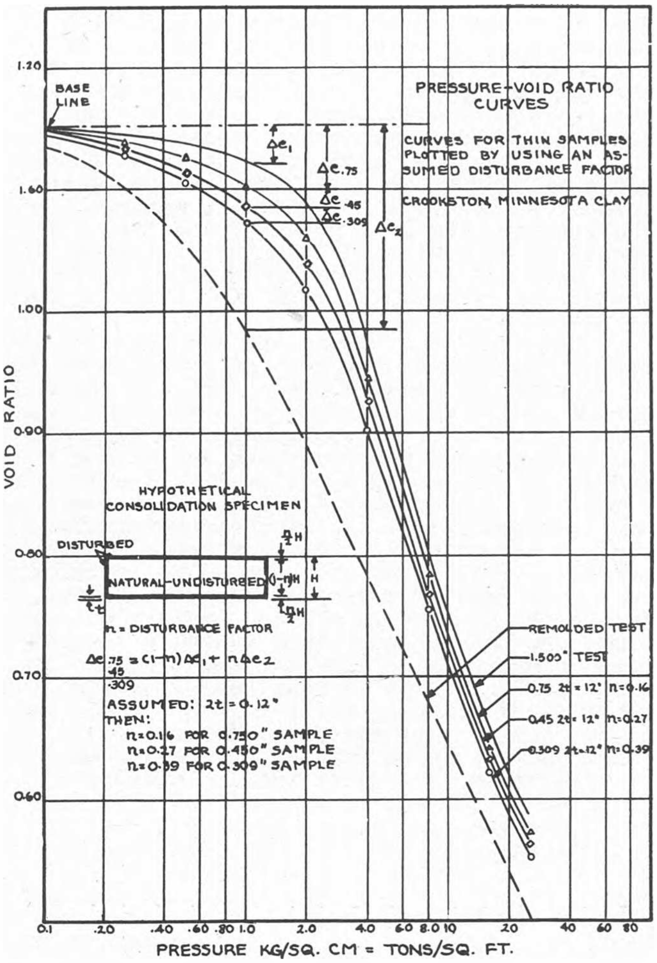


Consolidation Device

FIG. 4

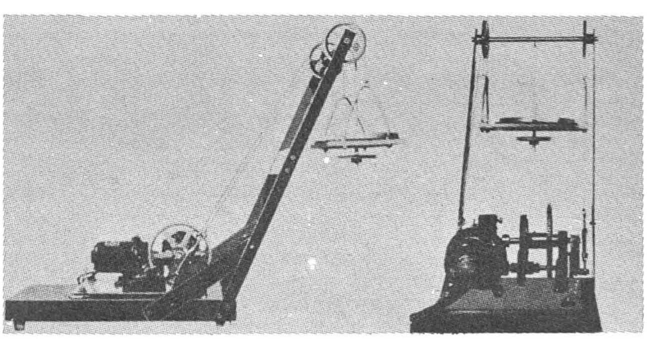
Typical results are shown by the curves in fig. 5. The differences between these curves have been established to be due primarily to sample remolding in the trimming operation. After a specimen has been trimmed in a lathe type device (fig. 16) sufficiently to fill the ring, it must be cut so that the top and bottom of the specimen are flush with and have the same thickness as the brass container ring. This operation, no matter how carefully carried out, causes a remolding which may alter the soil as much as 1/8" from the surface. In thin specimens, the volume of soil remolded is an appreciable part of the total, but in thick specimens ($1\frac{1}{2}$"), it is only a very small part. On the basis of curves for a completely remolded soil and the several thicknesses of specimens, a method of correction has been worked out to correct for disturbance of a test of a specimen of any thickness. When this correction factor is applied to the actual test data, an undisturbed curve is obtained.

Another project now in progress concerning soil consolidation characteristics involves the cyclic loading of soils. We know that the behavior of a soil subjected to intermittent loading is very different from its behavior when subjected to a purely static load, as evidenced by the many subgrade failures in highways, airports, and other structures. However, practically nothing is known concerning the properties of soil under repeated loading. We have therefore embarked upon a general study of the subject and, as a start, have attempted to reduce the problem to its simplest form for analysis. The questions we want answered are (1) how do the consolidation characteristics of soil differ under continuous and repeated static load increments of the same magnitude.



Effect of Specimen Thickness and Sample Disturbance on Consolidation Test Results

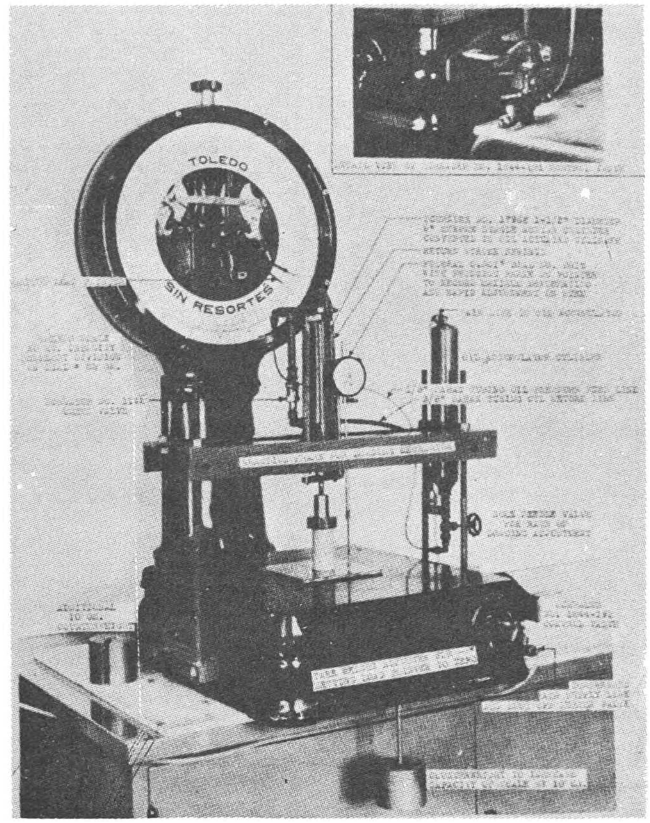
FIG. 5



Cyclic Loading Device

FIG. 6

(2) what is the effect of the frequency of repetition, that is, the number of cycles per minute, (3) what is the effect of the magnitude of the cyclic load, and what is the effect of the magnitude of the static load to which a cyclic load increment is added. One of the four cyclic loading devices used for this study is shown in fig. 6. A constant speed motor with a double reduction gear drives a set of gears which rotate two arms about each end of a shaft. To the end of the arms are attached two



Unconfined Compression Device (Air-operated) This machine is designed for rapid performance of large numbers of unconfined compression tests on soils. Strain or load can be applied at any desired rate. Release of load is very rapid to avoid crushing of test specimen by spring-back of scale after failure load is reached.

FIG. 7

cords which pass around the sheaves shown and connect with a rectangular rack. As the arms turn, the rack moves up and down, having a total travel of about four inches. The position of the rack is adjusted by two turnbuckles attached to the arms and cords so that the rack travels an equal distance below and above the weight hanger plate on the consolidation device lever system. Thus, when a weight is placed on the rack, and the rack moves vertically, the weight is placed on the hanger as the rack moves down and is picked up as the rack moves up. The weight is thus on the hanger for one-half of the time for one cycle. Each device has a double set of gears so that two speeds may be used, one with the load on ten seconds and off ten seconds, and the other with the load on thirty seconds and off thirty seconds. These two speeds were chosen only for the first series of tests in order not to introduce too many variables at first.

Tests with these devices are necessarily time-consuming. However. a number of interesting results have already been obtained. For hard clays the results of cyclic loading seem to be the same as for static loading; that is, the amount of consolidation or settlement obtained for a cyclic load is the same as for an equal static load applied for the same total time. Only when a large increment of cyclic loading is superposed on a static load higher than the preconsolidation load is there any breakdown of the clay structure evidenced by a squeezing out of the clay in the small clearance between the porous stone and the consolidation ring. For clayey silt, that is, a soil having the plastic properties of a lean clay but showing a small degree of dilatancy the phenomenen is quite different. Under a relatively small increment of cyclic loading (0.20 kg/cm^2) added to a small static load (0.10 to 0.80 kg/cm^2), a very definite "pumping" or squeezing action occurs after a few thousand cycles. It appears that the "pumping" is independent of the clearances between the porous stone and the cylinder. For two different clearances, and using a special thin retainer ring which is in direct contact with the stone and wall of the consolidation ring allowing no clearance, "pumping" occurs under the same conditions and also after only a few thousand cycles of load. It seems then that "pumping" is a basic phenomenon of complete remolding of the soil, which has little relation to the size of openings or cracks in the soil-confining medium.

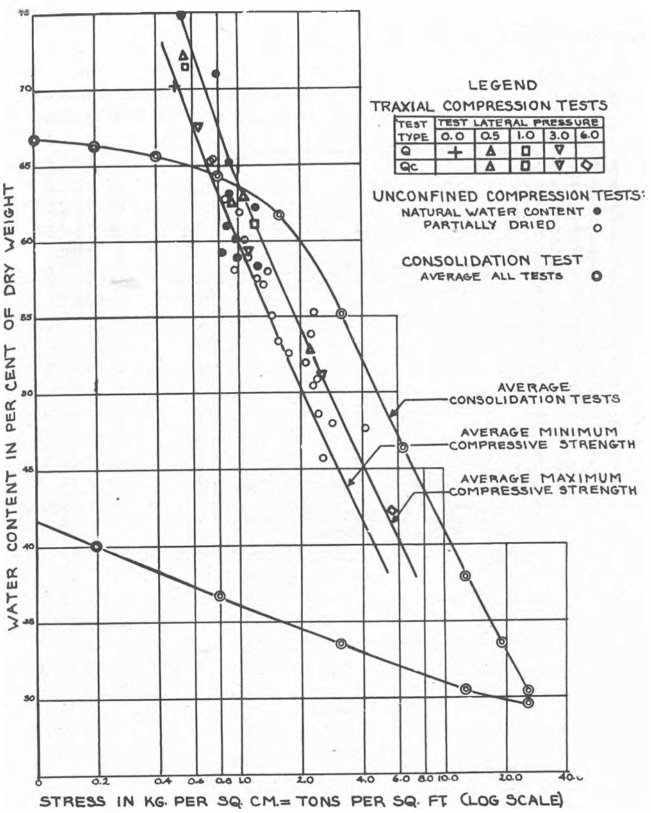
UNCONFINED COMPRESSION DEVICE

The unconfined compression device, shown in fig. 7, is made up almost entirely of standard parts. It is designed for making routine soil compression tests rapidly. Although complete stress strain curves may readily be obtained with this device, it is used mainly for obtaining only the failure load and strain at failure. The weighing device is a standard Toledo Scale calibrated in kilograms. The scale capacity is 20 kg but this may be extended to 40 kg by means of counterweights. Pressure is applied hydraulically be means of a single-acting air cylinder converted to oil for smoothness of operation. The oil is fed to the pressure cylinder from a half filled oil accumulator cylinder through a valve and a small (1/8" O.D, 1/16" I.D.) length of Saran tubing. Compressed air is admitted from a supply line to the top of the oil accumulator cylinder by pressing a threeway control valve. Air pressure of 100 lbs./sq. in. is more than is necessary to apply the load. The rate of loading is adjusted by the needle valve between the accumulator and the pressure cylinder. The small diameter of the oil pressure feed line makes it possible to obtain a wide range and a fine adjustment of the rate of loading. However, when the maximum load is reached it is necessary to release the load rapidly to avoid crushing the specimen. This cannot be done by allowing the oil to return to the accumulator through the small feed line and needle valve. For this purpose a larger (3/8" diameter) return line which by-passes the needle valve and the small feed line returns the oil from the pressure cylinder to the accumulator when air pressure is released. One-way flow of oil through the large oil return line is achieved by means of a ball checkvalve which closes when air pressure is applied, preventing flow through the tube. When air pressure is released, the ball check-valve opens and the return stroke springs push the oil back to the accumulator through the return line.

The procedure in testing a specimen is as follows: Place and center the test specimen on the platform under the piston. Adjust the tare weight adjustor to zero if needed (allowing for the small pressure of the dial indicator stem on the platform). Press the control valve and hold down for entire test. Open needle valve until piston just comes in contact with specimen and barely causes the load pointer to move. Close needle valve and adjust strain dial to zero by screwing the stem in or out. Start loading by adjusting needle valve to obtain the desired rate of loading. When the ultimate load is approached, the load indicator pointer will slow down and then come to a stop. When a complete stop is reached, release the control valve immediately. This exhausts the air in the accumulator and shuts off the air supply, thus releasing the load from the specimen. Read the maximum load from the maximum load pointer, and read the strain at maximum load from the dial gage. The dial gage has a friction brake which prevents the return of the dial when the actuating force is released.

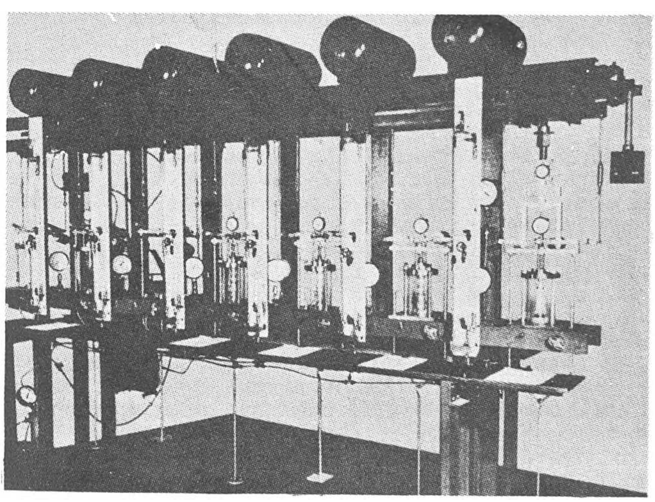
The rapid and convenient operation of this device has enabled the laboratory staff to carry on types of research requiring a large number of unconfined compression tests. One valuable result is the establishment of the relationship between water content and strength for saturated cohesive soils. Fig. 8 shows the result for a typical soil. Unconfined compression samples are tested at their natural water content and at various lower water contents achieved by allowing the samples to dry slowly in a humid room for varying lengths of time. When water content is plotted against unconfined strength (logarithmic scale) a straight-line or nearly straight-line relationship is obtained. This line is identical with the line obtained by plotting water content at the end of a triaxial test versus deviator stress (log. scale). It is immaterial whether the triaxial test is a quick unconsolidated, a quick consolidated, or a slow test. The end result is the same and is identical with the unconfined tests. Thus it has been demonstrated that strength is a function only of water content (or void ratio) and is independent of how the soil reached that water content, so long as it has not been remolded or previously dried below the shrinkage limit. Furthermore, the slope of the nearly straight line is parallel to the virgin curve portion of the water content-pressure curve of a consolidation test on the same soil. A practical application of these relationships exists in classifying soils. If the water content-strength relationships are established by unconfined tests for frequent intervals of depth from undisturbed samples, classification of soil type with depth may be made by grouping water-strength lines which lie close together into a single group. Then when the more elaborate triaxial compression or consolidation tests are made, the number of tests required may be kept to a minimum by selecting only one or two samples from each group. Check tests have shown that essentially identical results are obtained when several consolidation or series of triaxial compression tests are performed on soils from one group. The use of unconfined compression tests as a rapid means of soil classification has proved to be extremely valuable in our laboratory.

Another research project in which the unconfined compression device has been used is the study of the thixotropic strength characteristics of cohesive soils. It has been found by others that some soils which lose strength upon remolding regain it with the passage of time. We have studied a few soils for this effect, and although only preliminary results have been obtained, no significant regain of ultimate strength has been shown over a ten month period by the soils tested. It was found for a highly plastic montmorillonite clay that the original stiffness and brittleness, as mea-



Relation between Unconfined, Triaxial and Consolidation Test Results

FIG. 8

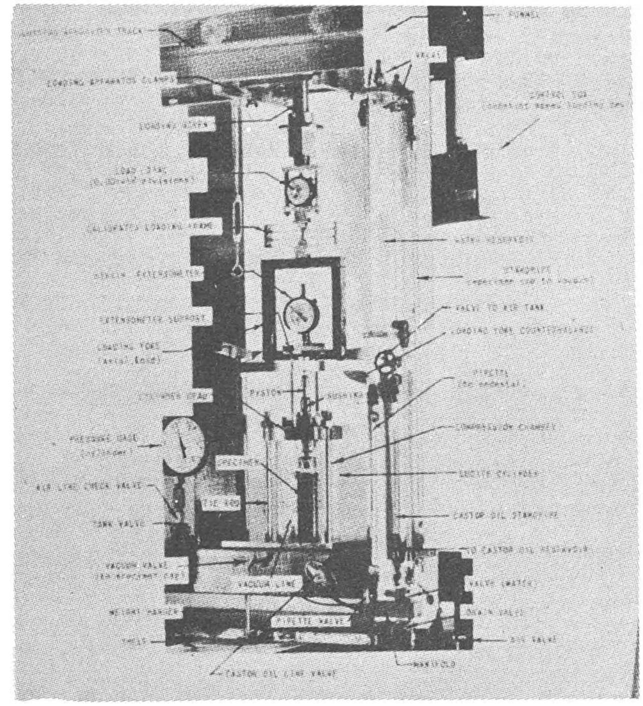


Triaxial Test Frame

FIG. 9

sured by the modulus of deformation and the strain at failure, increased very rapidly after remolding, and regained their original values in about six months.

Another unconfined compression test research project in progress is the study of the effect of changes in water content of saturated cohesive soils on the modulus of deformation of the soil. It appears that a straight-line relationship of water content-modulus (log plot) exists, similar to the water content-strength (log plot) relationship previously discussed.



Triaxial Compression Apparatus

FIG. 10

TRIAXIAL TESTING EQUIPMENT

The triaxial test frame (fig. 9) is equipped for performing seven tests simultaneously. In triaxial testing we are interested in the consolidation characteristics of a specimen as it consolidates under increments of hydrostatic pressure until it reaches full consolidation under the lateral pressure at which it is to be tested in compression. The consolidation process is time-consuming, so that a specimen may be in a divice from one day to a week while consolidating. Hence a number of devices are needed. At the right end of the frame, only quick unconsolidated tests are performed and therefore no drainage or equipment for measuring pore water is provided. The lucite cylinder containing the sample encased in a rubber membrane fits in a recess in the base plate which centers the equipment when the cylinder head is bolted down by the studs. A very carefully made lap-fitted piston fits into a bushing which is screwed into the cylinder head. The piston is made to fit the bushing so that it will just slide down slowly in the bushing from its own weight. Thus the load may be applied to the sample from outside the cylinder with practically no friction loss, and yet the piston fits tightly enough to keep the fluid in the pressure chamber (glycerine) from leaking past.

To obtain lateral pressure, air pressure is applied to the glycerine which transmits it to the membrane-encased soil specimen. The specimen may be tested under constant load or constant strain. For a constant load test, pressure is applied in increments by placing weights on a hanger suspended from a counterbalanced yoke arrangement. For a constant strain test (at the right-hand end, fig. 9), load is applied by means of a loading yoke and a specially designed proving frame. A gear-reduced motor, mounted on a carraige, drives a bevel gear which moves a screw vertically. The proving frame is attached to this screw.

It is so designed that its load-strain sensitivity is high for low loads, and is greatly reduced for higher loads. Thus sufficient load measuring accuracy is obtained for the entire range of loads that may be met in practice. In the photograph (fig. 9) the upper dial indicator measures load, and the lower dial indicator measures strain in the specimen. The carraige, proving frame, and load yoke can be moved to any position, when a specimen is ready for test.

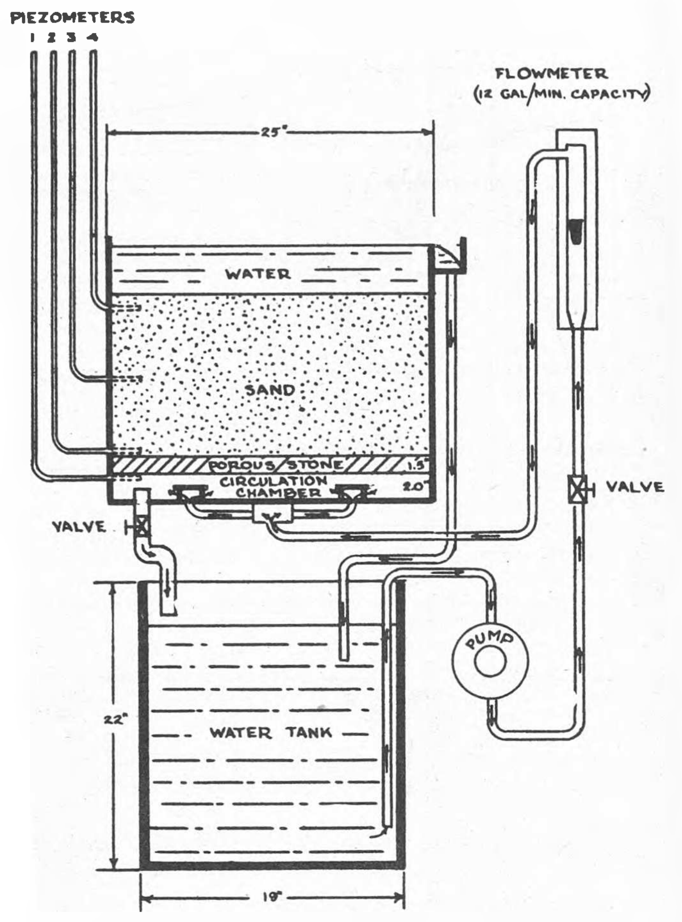
A close-up of one of the six devices for consolidated triaxial tests is shown in fig. 10. The cylinder, head, and load-application mechanism is the same as for the right-hand device used only for quick unconsolidated tests. In addition, these devices contain means for evacuating and saturating the specimen and for measuring the pore water volume squeezed out during consolidation. No making or breaking of connections is required to evacuate a sample, saturate it and adjust the water level in a pipette before applying lateral pressure. The entire process is controlled by turning the proper valves. A major feature of the triaxial test equipment is its convenience and ease of operation.

A research project now in progress using the triaxial equipment has as its objective the determination of pore water pressure at various points in a soil specimen which is under lateral pressure. Auxiliary equipment, using photoelectric cells, automatic air valves and a pressure recorder is used to obtain a continuous record of the variation of pore water pressure with time. A porous tipped hypodermic needle filled with water is injected into the soil specimen to the point where the pore water pressure measurements are desired. The needle leads through a small tube to a pipette of small diameter. The water level in the tube is adjusted to a point at which is focused the light beam of an electric eye system. As lateral pressure is applied to the specimen, the pore water pressure in the soil tends to squeeze the water out through the hypodermic needle and cause it to rise slightly in the pipette. But a rise in the water level in the pipette breaks the "electric eye" circuit and operates a solenoid air valve which in turn admits air into the pipette until the air pressure balances the water pressure. A similar "electric eye" and solenoid air valve releases air pressure when the level falls. A continuous balance of pressure is maintained and the water level in the pipette is kept constant within a very small distance. Thus, practically no water flows in or out of the hypodermic needle. The varible air pressure required to keep a continuous balance is automatically recorded on a chart by a pressure recorder.

Tests with this apparatus are now in their initial stages. Although in some instances very rapid response of pore water pressure to lateral pressure has been recorded, considerable difficulty has been experienced in eliminating air completely from the system. Any air in the water system will cause a lag in the pore water pressure record.

QUICKSAND TANK

The quicksand tank has proved to be the most popular apparatus in the laboratory. It is designed for both demonstration and research. It is two feet square in area, and made almost entirely of lucite, so that it is transparent on all sides. Fig. 11 is a diagramatic sketch of the apparatus. Water pumped



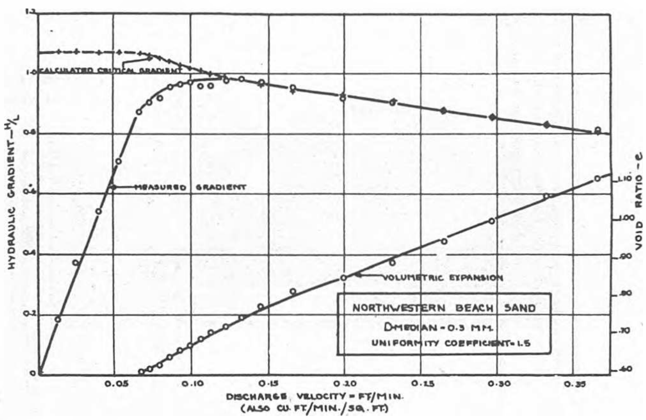
Quicksand Tank

FIG. 11

from the supply tank passes through a flow meter into the bottom of the test tank. The flow is divided into four inlets leading to the circulation chamber. At each inlet, baffle plates disperse the water so that the flow is distributed evenly across the area of the tank. Water flows upward through a porous stone and through the sand. It is discharged into a trough and returned to the supply tank. The heads at several elevations in the tank are indicated by piezometers tapped into the side of the test tank to the supply tank. Recirculating the water from a supply tank has the advantages of constant temperature, constant controlled pressure, and freedom from entrapped air.

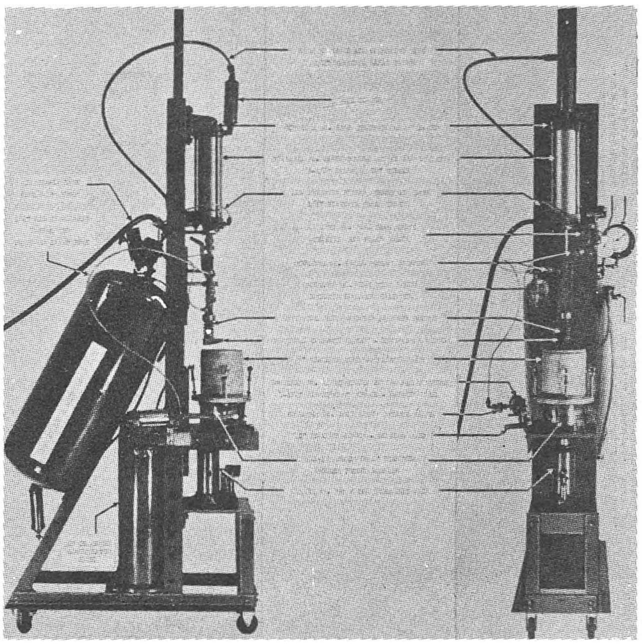
As a demonstration apparatus, the tank is used to show that, when upward flow occurs, the bearing capacity of the sand is reduced and, when the upward seepage forces are equal to the downward submerged weight of the sand, its shearing strength, and hence bearing capacity, is zero. Also when water flows downward, the seepage forces increase the normal pressure between the soil grains and hence increase the shear strength. In addition, when the sand is loose and water drained to just below the sand surface, a heavy weight can be sustained by the sand. However, when the sand is vibrated or jarred by poking a large rod into it, it suddenly becomes liquified and the weight sinks out of sight.

When the weight of dry sand and its specific gravity is known, the void ratio under any flow condition can be computed from the vol-



Relation between Hydraulic Gradient and Seepage Velocity for Upward Flow of Water through Sand

FIG. 12



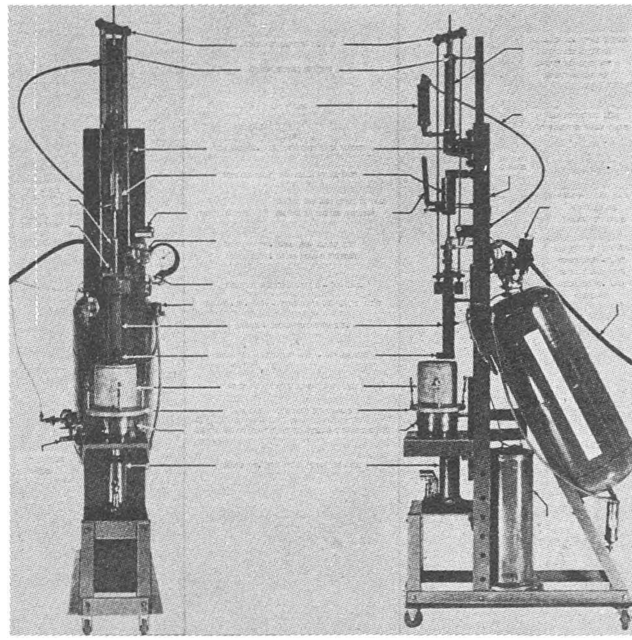
Kneading Compaction by Northwestern Air Operated Soil Compactor

FIG. 13

ume of the sand. Knowing in addition the quantity of flow from the flowmeter reading and the loss of head between piezometers from piezometer readings, several interesting relations between soil properties can be demonstrated. A curve for such a test on a fine uniform sand is shown in fig. 12. As flow increases, the relation between the hydraulic gradient and discharge velocity is a straight line, verifying Darcy's Law. However as the critical gradient is approached, there is some expansion of sand volume, which increases its permeability. This expansion also decreases the calculated critical hydraulic gradient since the void ratio increases.

$$\text{(Critical gradient} = \frac{\text{Specific Gravity} - 1}{1 + \text{void ratio}}\text{).}$$

When all the sand has become "quick" and is fully buoyed up, the calculated critical and the measured hydraulic gradient are identical which verifies the theoretical conception of



Impact Compaction by Northwestern Air Operated Soil Compactor

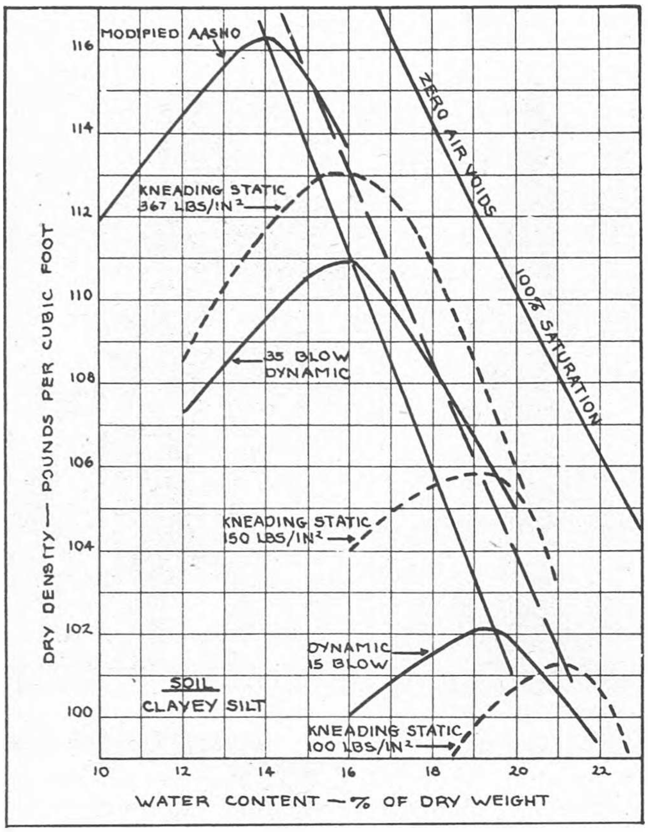
FIG. 14

quicksand. It is interesting to note that as flow is increased, the hydraulic gradient decreases, since for each increment in quantity of flow a new equilibrium position is reached at a higher void ratio, requiring a smaller hydraulic gradient to cause flow. This relation will continue until the "Stokes" velocity is reached for the finest particles in the sand, after which the sand will be gradually washed out as the flow increases. It is interesting to note that laminar flow obtains throughout the entire process represented in fig. 12. Curves similar to fig. 12 have been obtained for several other sands, and the same general relationship exist.

In addition to the above experiments on quicksand, the quicksand tank has been used for a model tank to determine the adequacy of a gravel filter in preventing sand from being washed into it from below due to upward flow.

COMPACTION TEST EQUIPMENT

An extensive research project in soil compaction is now in progress in the laboratory. The project involves a comparison of compaction under impact (Standard Proctor compaction, modified Proctor, etc.) and compaction under a kneading static pressure similar to the pressure applied by a sheepsfoot roller. For this purpose a special apparatus has been constructed (fig. 13). The mechanism is operated entirely by air pressure. Air pressure from a constant pressure tank is admitted into a double-acting air cylinder. The piston and shaft to which a triangular shaped foot is attached are pushed down against the soil. Upon contact with the soil, the foot exerts a given constant pressure determined by the value of the constant pressure preset by the regulator in the supply tank. The bearing surface of the foot is slightly rounded and it is connected to the piston shaft by a universal joint which has a stiff spring around it. Thus when the foot presses on the soil it can rotate somewhat when meeting non-



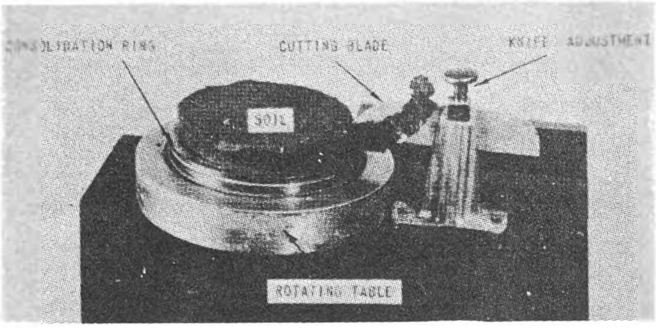
Comparison of Dynamic and Kneading Static Compaction

FIG. 15

uniform resistance, and a kneading action is obtained. After a few seconds contact with the soil, the piston pressure is released (by an automatic air-time valve) and the piston is pushed up by constant back-pressure in the double acting cylinder. As the foot returns to starting position it kicks an air valve which lets pressure into the double acting cylinder and the cycle is repeated. As the foot rises from the soil, the soil mold which rests on a thrust bearing platform arrangement, is automatically rotated one-tenth of a revolution, equivalent to the segment shaped area covered by the foot. The entire process is automatic and runs continuously as long as a hand air valve is pressed, and stops after the completion of a cycle when the hand valve is released.

For the impact type compaction the above apparatus is modified as shown in fig. 14. A twenty-pound weight with a triangular foot is lifted nine inches by means of a ratchet arrangement on a cylinder piston-rod yoke. At a nine-inch lift the weight is released. As the soil fills the mold, the weight catches higher and higher on the ratchet, and still provides a nine-inch drop. This weight and drop give an energy of 180 inch lbs. per blow, the same as for modified Proctor compaction, which requires a 10 lb. hammer to drop 18 inches. The other arrangements and operations are unchanged from the kneading compaction device. To change the machine from one type of compaction equipment to the other requires about twenty minutes.

A comparison of the dry density-water content curves for various compactive efforts for the two types of compaction is shown in fig. 15. It is seen that the kneading type of



Consolidation Specimen Trimming Device

FIG. 16

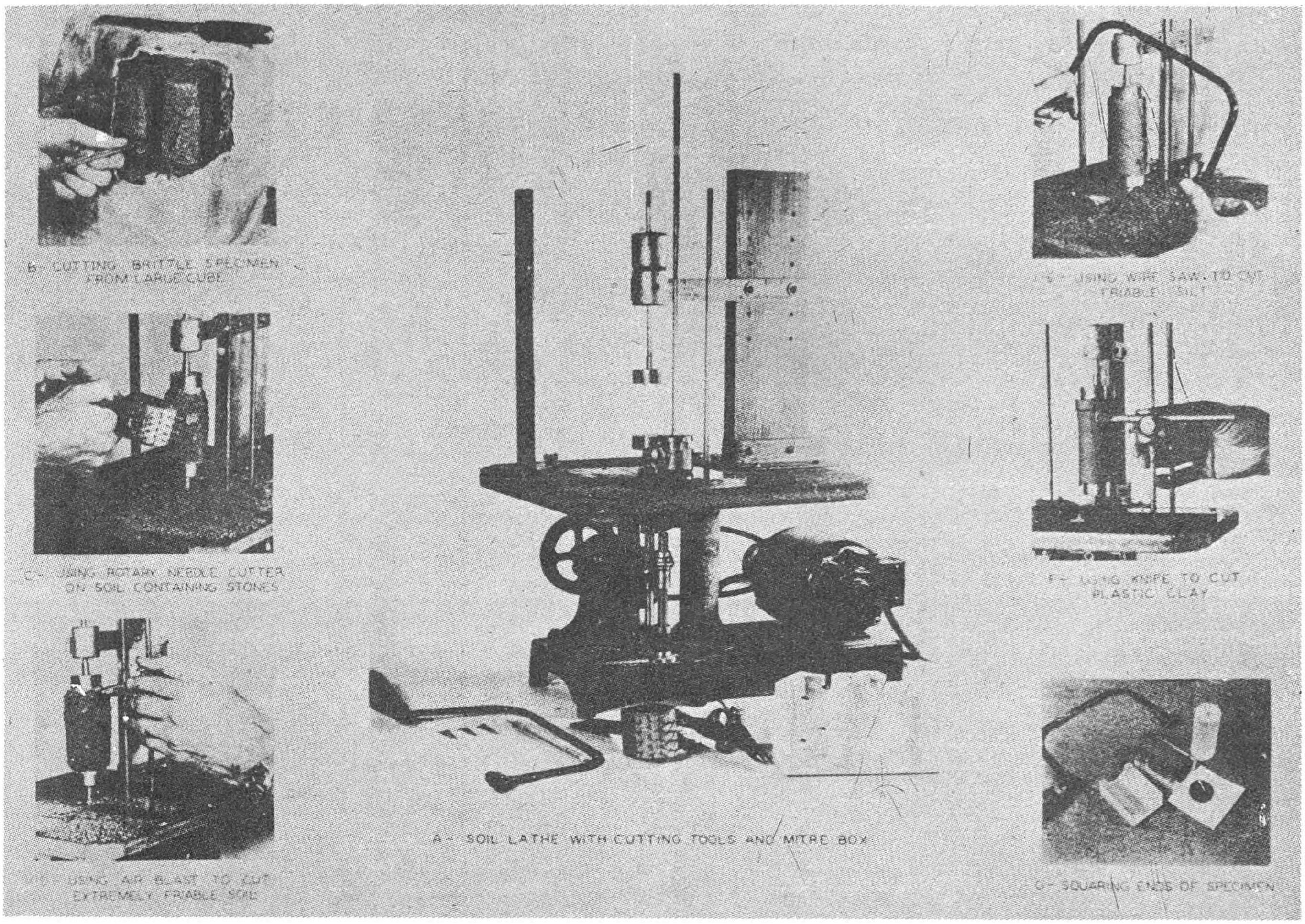
compaction brings the curve on the wet side of optimum water content closer to zero air voids than the impact type of compaction. Thus the kneading action is more efficient in pushing the air out of the soil. However for a clayey sand, in which air is more easily removed, there is practically no difference between the position of the two families of curves with respect to the zero air voids curve.

Other studies being made in connection with the compaction research project are the determination of lateral pressures and the consolidation, unconfined strength, and triaxial strength characteristics of compacted soil. For study of lateral pressures, special split molds are used, whose three segments are held together with calibrated straps on which electric wire strain gages are attached. The lateral pressure is measured by the hoop tension produced in the straps as the soil is compacted in the mold. It has been found that rather large residual lateral stresses exist in compacted soils, and that the pressure decreases somewhat with time after compaction and reaches a constant value. Soaking the compacted specimen may cause the lateral pressure to increase as much as fifty per cent. I has also been found that, as the molding water content increases above the optimum water content, the initial lateral pressure after compaction decreases rapidly.

SOIL SPECIMEN PREPARATION

The preparation of soil specimens for testing requires considerable skill and ingenuity. The more one handles soils, the more one realizes that each soil is unique and requires different methods of treatment in specimen preparation. Soft clays may be cut like cheese with a wire saw, but extra precaution must be taken not to remold the soil or disturb its structure. Harder clays become more brittle and sometimes may be cut more easily with a knife. Very hard soils with many stones may be cut most easily with an abrasive tool.

Consolidation test specimens are prepared by using the device shown in fig. 16. The circular base rests on ball bearings and can be rotated freely about its vertical axis. The standard consolidation test ring fits into the base and is rotated with it. A circular plate held up by adjustable spring action just fits inside the consolidation ring and serves to support the soil specimen to keep it from sagging out of shape as it is trimmed to fit the ring. The trimming tool clamped on a fixed post has a groove in it, so that when pushed up against the consolidation ring, a



Compression Test Specimen Trimming Lathe

FIG. 17

sample exactly the size of the ring is cut as the consolidation ring is rotated. After the sample has been trimmed to fill the ring it is carefully cut off on the top and bottom and finished off to the exact thickness of the ring by means of a straight edge.

For preparation of unconfined or triaxial test specimens, a special "soil lathe" has been developed in this laboratory (fig. 17A). A soil sample is trimmed roughly to a size a little larger than than required for a test, and is placed in the lathe. The lathe speed can be adjusted to the type of soil. A loose belt and loose friction drive permits rotation to stop and the belt to slip when a stone or hard spot is hit in trimming. This helps prevent splitting a brittle soil, or tearing a groove through a plastic soil. Fig. 17B shows the method of trimming a brittle soil from a large cube sample. A grooving tool is used to scrape away a groove on each side of the sample. In many brittle soils using a knife for cutting causes the soil to split in uncontrolled directions. Fig. 17C shows the soil lathe in operation and a hard brittle soil with many stones being cut by a rotary needle cutter. The needles actually pick the stones out. When very close to final size, final trimming is done by a wire saw. A rather unusual, extremely friable, brittle, and almost dry soil originating from pumice defied all methods of trimming until an air blast was tried as shown in fig. 17D and found successful in trimming the soil almost to final size. Final trimming was done with the knife of 17F. Fig. 17E shows the method of trimming a friable silt. This method as well as that shown in 17F is applicable to most clays. After final trimming, the ends of the specimens are squared as shown in Fig. 17G.

ACKNOWLEDGEMENTS

The author acknowledges the many suggestions and ideas, as well as the encouragement given him by Professor P.C. Rutledge, Chairman of the Civil Engineering Department, in the design and construction of the Soil Mechanics Laboratory. Much of the apparatus in this laboratory has developed directly from apparatus originally designed and constructed by Professor Rutledge in the laboratory at Purdue University and from the laboratory developments by Professor Arthur Casagrande and his staff at Harvard University. All research projects in this laboratory are conducted under the direction of the writer, Professor Rutledge and Professor H.P. Hall. Acknowledgement is also due to the following graduate students and research assistants for their contribution to the research results reported herein: Mr. Theodore Van Zelst, for his study on the effect of consolidation test specimen thickness on test results, for his work on the development of the pore water pressure apparatus, and his assistance in the study of cyclic loading of soils: to Mr. John L. McRae for his work on

the soil compaction study and his development of specimen preparation techniques; to Mr. Louis Berger and Mr. John P. Gnaldinger for their study of the thixotropic properties of certain clays.

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COMPREHENSIVE REPORT ON THE EARTH MATERIALS LABORATORIES IN THE UNITED STATES

Subcommittee 3 of U.S. National Committee

SUMMARY

This paper comprises a report by Subcommittee 3 of the U.S. National Committee on Soil Mechanics regarding the activities of laboratories of the United States in the field of soil mechanics. The committee submitted a questionnaire to all educational, state, federal, and private institutions who might be engaged in earth materials testing. Of the 244 questionnaires submitted, 144 institititions indicated that they were actively participating in this field of work for teaching, design, construction, or consulting purposes. The size and equipment for laboratories vary from small units designed for teaching purposes to large, fully equipped units for teaching, design, construction, consulting, and research work. From these latter laboratories considerable information was obtained on new equipment and testing techniques and research programs in soil mechanics.

I. INTRODUCTION

Subcommittee 3 of the United States National Committee on Soil Mechanics was appointed by the Chairman of the National Committee during April 1947 to investigate and report on United States laboratories, personnel, equipment, and testing techniques in the field of soil mechanics. This committee consisted of R.F. Blanks, x) Chairman, and Robert Hennes, xa) D.W. Taylor, xb) W.J. Turnbull, xc) and A.W. Johnson, xd) members. The subcommittee submitted a questionnaire to 244 educational, state and federal, and private institutions engaged in soil mechanics work. Two hundred eighteen answers were received. This questionnaire covered all of the pertinent facts related to the subject. The results from the questionnaire disclosed three general types of laboratories in this country. These are (1) small laboratories in educational institutions which are used for instructional purposes only; (2) laboratories in all catagories of institutions which are used for the more common and accepted tests in teaching,designing, constructing, and consulting work; and (3) the larger laboratories which are interested in research work as well as standard testing for teaching, designing, constructing, and consulting purposes. From these latter laboratories a wealth of information was obtained on new equipment, testing techniques and research programs for the more complex phases of soil mechanics.

Part II of this report describes, briefly, the various types of laboratories in the United States. Part III is devoted to a detailed discussion of laboratory testing equipment and laboratory testing techniques for various tests as used throughout the United States.

The subcommittee wishes to express its appreciation to W.G. Holtz xe) and members of his staff for their work in assembling the questionnaire data and preparing this report.

II. GENERAL REVIEW OF UNITED STATES LABORATORIES

Table 1 is a summary of the information obtained from the questionnaire, and includes all laboratories from which data was secured. This table includes the identification of the institutions having soil laboratories for engineering purpose, the size of the laboratories, the personnel directing the laboratories, the equipment available for testing, the general procedures followed, and notes on any research activities.

Seventy-nine colleges and universities indicated that they maintained earth materials testing laboratories. These laboratories ranged from small units which were used primarily for instruction purposes and were equipped with a minimum amount of equipment for standardized tests to large, well equipped units interested in teaching graduate as well as undergraduate courses and actively participating in complex research projects.

Information was received from thirty-seven state agencies which maintained soils laboratories. Here again the size and activities of the laboratories varied considerably. The state institutions were primarily interested in soil problems related to highway construction. While

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xc) Chief, Soil Division, U.S. Waterways Experiment Station, Vicksburg, Mississippi.
xd) Engineer of Soils and Foundations, Highway Research Board, Washington, D.C.
xe) Head, Earth Materials Laboratory, U.S. Bureau of Reclamation, Denver, Colorado.

in general, most of these agencies maintain laboratories for design and construction control purposes, seven organizations indicated that they were active in the research field.

Ten Federal Government agencies maintain laboratories for earth materials testing. While some agencies maintain small laboratories for standard testing purposes, the Bureau of Public Roads, Bureau of Yards and Docks, Bureau of Reclamation, the Panama Canal, and the Corps of Engineers maintain large, well equipped laboratories for design, construction, and research work.

Many private institutions maintain testing laboratories as an aid to design, construction, and consulting work. Eighteen such agencies indicated their activity in this field. These laboratories also vary from small units for standard tests to rather large units which are equipped to perform the more complex soil tests.

The information received, as shown in Table 1, reveals that of 144 laboratories listed, 49 are equipped to perform standard tests only, and 95 are equipped to perform the more complex tests and carry out valuable research programs in addition to standard test procedures.

III. DETAILS OF LABORATORY EQUIPMENT AND TECHNIQUES

A. GENERAL

The following part is devoted to a detailed discussion of a number of laboratories, their equipment, and their techniques. For the sake of clarity, this discussion is divided into sections related to individual tests such as permeability, consolidation, etc., and one section related to general facilities. It is not the intent of the authors to single out any one laboratory or any group of laboratories in this discussion. It was necessary to rely on the information submitted to the subcommittee; the completeness of the data obtained, and the exhibits suitable for reproduction therefore had a bearing on the material selected for these discussions. Further, it is not the intent of the subcommittee to recommend any test equipment or test procedures, but to point out the most common practices and the variations in equipment and techniques which may be found in the earth materials testing laboratories of the United States.

B. MECHANICAL ANALYSIS

1. General

The mechanical analysis is the quantitative determination of the grain size distribution in a soil. The data have value because gradation has been generally correlated with probable soil mass behavior through empirical means and in many cases gives good indications of the permeability, stability, and workability of the soil. Also, limits of gradation may be specified for certain conditions, particuealarly for filters, drains, roadway base course materials, and possibly for pervious shell or transition materials for earth dams.

Mechanical analysis includes:

1) Determination of gravel sizes on coarse screens,
2) Sieve analysis on coarse and fine sand down to No. 200 size,
3) Hydrometer analysis of the fines passing the 200-mesh sieve.

The material passing the 200-mesh sieve is analyzed by the rate of sedimentation in water, using the hydrometer as the means of measurement and Stokes' law as the basis for the computation of the particle sizes. These three determinations are combined into a total analysis, and the results are plotted on semilog graph sheets.

Mechanical analysis apparatus used throughout the United States are quite standardized. Screens from 6-inch openings down to No. 200 (74-micron opening) are used in various combinations and sets. Either hand or mechanical shakers are provided with the screen for sifting the soil samples. Hydrometer, glass graduates, and stirring apparatus with dispersion cups are provided for the hydrometer analysis. Other miscellaneous equipment such as thermometers, stop watches, balances, drying ovens, and dessicators are used for the mechanical analysis test.

2. Testing Equipment

Field samples can be screened in the field to separate the rock and soil fractions, or the entire sample may be shipped to the laboratory. At the Bureau of Reclamation the rock is screened on 6-inch, 3-inch, 1½-inch, 3/4-inch, 3/8-inch, and No. 4 screens, with the mechanical screens and equipment shown in Figure 1.

The soil fraction (usually materials smaller than 1/4-inch or No. 4 size) is further separated on a nest of screens, actuated by hand or mechanical means. Figure 2 shows a series of Tyler sieves, Nos. 4, 8, 14, 28, 48, 100 and 200, and the Rotap machine for sifting the samples. The Board of Water Supply for the City of New York also uses the Tyler series of sieves for mechanical analysis, United States Standard sieves are used at the University of Utah, Texas A&M College, the University of Maine, and the Georgia State Highway Department.

The minus No. 200 material (silt and clay) is analyzed by means of hydrometers placed in soil supensions. Two types of hydrometers are in use: one reading in grams of material per liter of suspension as used by the University of Michigan and the Bureau of Reclamation; the other graduated as specific gravity of suspension is used by the New York Board of Water Supply and the University of Notre Dame. A Bouyoucos hydrometer calibrated in grams per liter of suspension is shown in Figure 3.

3. Test Procedure

a. Apparatus. The apparatus may consist of the following:

1) Set of coarse screens, 6-inch to No. 4,
2) Set of sieves, Tyler or United States Standards, No. 4 to No. 200,
3) Stirring apparatus with dispersing cup equipped with baffles. See Figure 4,
4) Hydrometer,
5) Glass graduate 18 inches in height and 2½ inches in diameter with a graduated volume of 1,000 milliliters,
6) Thermometers, stop watches, beakers, evaporating dishes, ovens, etc.

b. Testing

1) Screen the entire sample on a nest of coarse screens, such as 6-inch, 3-inch, 1½-inch, 3/4-inch, 3/8-inch, and No. 4 to separate and grade the rock fragments from the soil matrix.

2) Split the large sample of soil matrix down to about 500 grams or less for further analysis. Dry, weigh, and wash this portion on a No. 200 screen to separate the sand sizes from the silt and clay sizes. That partion retained on the No. 200 screen is dried and sieved through a nest of sand size screens, say, Nos. 8, 14, 28, 48, 100, and 200, by hand or mechanical means. Time for screening varies from 8 to 20 minutes. The separate portions retained on each screen are weighed and recorded.

TABLE 1

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA[1]

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment[2]	Standard	Specialized or new developments
EDUCATIONAL INSTITUTIONS:								
Univ. of Akron	Akron, Ohio	Teaching	Prof. B. W. Boguslavsky	1	350	Std. properties	Housel Manual	None
Univ. of Ala.	Univ., Ala.	Teaching	Prof. J. M. Faircloth	1	(Small)	Std. properties for highways and Fnds.	(Not known)	None
Univ. of Ariz.	Tuscon, Ariz.	Teaching	Prof. J. C. Park	1	-	Std. properties, shear, consolidation	(Not known)	None
Univ. of Calif.	Berkeley, Calif.	Teaching, research	Prof. H. E. Davis	5	1,400	Std. properties, consolidation, direct and triaxial shear	ASTM	None
Calif. Institute of Tech.	Pasadena, Calif.	Teaching, research	Prof. F. J. Converse	1	1,100	Std. properties, consolidation, direct and triaxial shear	ASTM, CBR, Proctor	None
Carnagie Institute of Tech.	Pittsburg, Pa.	Teaching	Prof. C. W. Muhlenbruch, Jr.	1 (or more)	6,400	(Not known)	(Not known)	None
Case Inst. of Tech.	Cleveland, Ohio	Teaching and research	Prof. Oscar Hoffman	1	750	Std. properties, consolidation, direct and triaxial shear	ASTM and AASHO	Triaxial shear tests on saturated cohesive soils
Catholic Univ. of America	Washington, D. C.	Teaching	Edw. S. Barber	1	(Public Roads Res. Lab.)	-	-	-
City College of N.Y.	New York, N.Y.	Teaching	Prof. L. W. Engler and Prof. P. Hartman	3	2,000	Std. properties, MIT consolidation, direct and triaxial shear	ASTM, Proctor and others	None
Clarkson College of Tech.	Potsdam, N.Y.	Teaching and research	Prof. W. H. Allison	1	600	Std. properties, consolidation, direct and triaxial shear	ASTM and others	None
Clemson Agri. College	Clemson, S. C.	Teaching	Prof. C. C. Norman	2 (or more)	2,500	Std. properties, consolidation, direct and triaxial shear	ASTM, AASHO, and others	(In process of development)
Colo. A&M College	Ft. Collins, Colorado	Teaching	Prof. R. L. Lewis	3	1,250	Std. properties, consolidation, and direct shear	(Not known)	None
Univ. of Colo.	Boulder, Colo.	Teaching	Prof. W. H. Thoman	3	1,200	Std. properties	ASTM, AASHO, CAA	None
Columbia Univ.	New York, N.Y.	Teaching, research, advisory, & consulting	Prof. D. M. Burmister	2	900	Std. properties, consolidation, (10) direct(2) triaxial shear	AASHO, CBR	Seepage studies
Univ. of Conn.	Storrs, Conn.	Teaching & research	Prof. E. L. Gant	(Varies)	720	Std. Properties, consolidation, direct and triaxial shear	ASTM, AASHO, and others	None
Cooper Union	New York, N.Y.	Teaching	J. C. Mahle	1	2,500--(In conjunction with State Highway Testing Lab.)	Std. properties, consolidation (5), direct (2), and triaxial shear (1)	"Notes on soil testing" Harvard Univ., CBR	None
Cornell Univ.	Ithaca, N. Y.	Teaching & research	Prof. E. K. Hough, Jr.	1	2,500	Std. properties	(Not known)	None
Duke Univ.	Durham, N. C.	Teaching	H. C. Bird	2	1,150	Std. properties, consolidation, direct shear (4), triaxial shear (2), and photoelastic.	Proctor, CBR, and others	None

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA1/

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment2/	Standard	Specialized or new developments
Univ. of Fla.	Gainesville, Fla.	Teaching & research	Prof. L. J. Ritter	3	1,000	Std. properties, consolidation, direct & triaxial shear	USED, triaxial shear, CBR, ASTM, AASHO, MIT, consol.	None
Ga. School of Technology	Atlanta, Ga.	Teaching	Prof. T. H. Evans	2	400	Std. properties, consolidation(2), & triaxial shear(1), unconfined compression	(Not known)	Stability of foundations (planned)
Harvard Univ.	Cambridge, Mass.	Teching, research & consulting	Dr. Karl Terzaghi Dr. A. Casagrande	10 (or more)	4,000	Std. properties, consolidation(15), direct shear(1), triaxial shear(8), dynamic loading devices, etc.	"Notes on Soil Testing" Harvard, War Dept. Bul. TB5-253-1	Stress--deformation and strength characteristics of soils by means of triaxial and unconfined compression tests, & strength characteristics under dynamic loading
Ill. Institute of Tech.	Chicago, Ill.	Teaching & research	Prof. R. G. Fehrman	3	600	Std. properties, consolidometer(1)	(Not known)	(In process of development)
Univ. of Ill.	Urbana, Ill.	Teaching & research & consulting	Dr. R. B. Peck	Full time--4 Part time or consulting--6	2,250	Std. properties, consolidations, direct & triaxial shear, unconfined compression	(Not known)	Changes in characteristics of clays with time.
Iowa State College	Ames, Iowa	Teaching & research & construction	Prof. M. G. Spangler	7	5,500	Std. properties, consolidation, direct & triaxial shear	AASHO, USED, Harvard, & CBR	Cone bearing test, soil-water tension test
State Univ. of Iowa	Iowa City, Iowa	Teaching & research	John O'Mara	1	375	Std. properties, consolidation, direct & triaxial shear.	(Not known)	None
Johns Hopkins Univ.	Baltimore, Md.	Teaching	Dr. W. C. Boyer	3	1,500	Std. properties, consolidation, direct & triaxial shear	ASTM & "Notes on Soil Testing", Harvard	None
Kansas State College	Manhattan, Kans.	Teaching	Prof. H. H. Munger	2	525	Std. properties, consolidation, direct & triaxial shear	AASHO, and others	None
Univ. of Kans.	Lawrence, Kans	Teaching & research	Prof. D. D. Haines	2	800	Std. properties, consolidation, direct & triaxial shear	ASTM and others	None
Lehigh Univ.	Bethlehem, Pa.	Teaching	Prof. C. D. Jensen	2	800	Std. properties, consolidation, & shear	ASTM and others	None
La. State Univ.	Baton Rouge, La.	Teaching & commercial	Dr. W. P. Wallace	1	400	Std. properties	ASTM and others	None
Univ. of Maine	Orono, Maine	Teaching, research & construction	Dr. Hamilton Gray	2 to 6	1,659(In conjunction with State Hy. Testing Lab.)	Std. properties, consolidation, direct & triaxial shear	"Notes on Soil Testing" Harvard, ASTM, and others	None
Univ. of Md.	Baltimore, Md.	Teaching, & research	Prof. E. S. Barber	1	1,100	Std. properties, consolidation, direct & triaxial shear	ASTM and others	None

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA[1]

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment[2]	Standard	Specialized or new developments
Mass. Institute of Tech.	Cambridge, Mass.	Teaching & research	Prof. D. W. Taylor	8	2,400	Std. properties, consolidation, direct & triaxial shear	MIT	Soil Solidification Project--Mech. & chem. tests on synthetic polymers, silicates & base exchange clays used as bonding agents.
Mich. State College	East Lansing, Mich.	Teaching & research	D. J. Hall	2	-	Std. properties, consolidation, & direct shear	ASTM & Housels Testing Manual	Vibratory consolidation & stabilization procedures & practices
Univ. of Mich.	Ann Arbor, Mich.	Teaching & research	Prof. W. S. Housel	16 full time 20-30 part time	1,300	Std. properties, consolidation, direct & triaxial shear	ASTM & Housels Testing Manual	
Univ. of Minn.	Minneapolis, Minn.	Teaching	Prof. M. S. Kersten	1 to 4	1,300	Std. properties, consolidation, direct & triaxial shear	AASHO, "Notes on Soil Testing" Harvard	Thermal conductivity & specific heat of soils studies
Miss. State College	State College, Miss.	Teaching & research	Prof. E. D. Myers	2	1,000	Std. properties	ASTM	None
Univ. of Miss.	University, Miss.	Teaching, research & construction	Dr. L. H. Johnson	4	5,216	Std. properties, consolidation, direct & triaxial shear	ASTM, "Notes on Soil Testing" Harvard	(In process of development)
Univ. of Missouri	Columbia, Missouri	Teaching & research	Prof. H. A. LaRue	(Varies)	6,300	Std. properties	ASTM	(No active program at present)
Mo. School of Mines & Metallurgy	Rolla, Mo.	Teaching	Prof. E. W. Carlton	(Varies)	1,280	Std. properties, direct shear	AASHO, ASTM, CBR	None
Univ. of New Hampshire	Durham, N. H.	Teaching & research	Prof. R. R. Skelton	1	1,000	Std. properties, consolidation(2), triaxial shear(1)	"Notes on Soil Testing" Harvard	None
N. Y. Univ.	New York, N. Y.	Teaching, consulting	Dr. A. A. Warlam	3	1,200	Std. properties, consolidation(6), direct shear (1)	ASTM, CBR	None
N. Dakota Agric. College	Fargo, N. Dak.	Teaching & research	Prof. J. A. Oekey	3	3,000	Std. properties	ASTM, AASHO	None
Univ. of N. Dak.	Grand Forks, N. Dak.	Research & advisory	Prof. E. L. Lium	1	2,000	Std. properties	(Not known)	None
Northwestern Univ.	Evanston, Ill.	Teaching & research	Dr. P. C. Rutledge	7	2,325	Std. properties, consolidation(8), triaxial shear(7)	(Not known)	None
Univ. of Notre Dame	Notre Dame, Ind.	Teaching	Prof. L. D. Graves	2	432	Std. properties, consolidation, direct shear	AASHO, CBR, Proctor	Photoelastic investigation of stresses in foundation soils.
Ohio State Univ.	Columbus, Ohio	(See State Highway Department--Ohio)						
Oklahoma A&M	Stillwater, Okla.	Teaching, research advisory	R. E. Means	2	720	Std. properties, consolidation, triaxial shear	(Not known)	(Not known)
Oregon State College	Corvallis, Oregon	Teaching, research & advisory	Dr. C. A. Mockmore	7	1,800	Std. properties, direct shear	ASTM, Housel	None
Univ. of Okla.	Norman, Okla.	Teaching, research	Prof. J. W. Keeley	1	(Small)	Std. properties, consolidation, triaxial shear	AASHO, ASTM, others	None

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA[1]

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Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment[2]	Standard	Specialized or new developments
Pa. State College	State College, Pa.	Teaching, research & advisory	Prof. R. E. Minshall	2	3,000	Std. properties, consolidation, direct & triaxial shear	(Not known)	Photoelastic apparatus
Univ. of Pittsburgh	Pittsburgh, Pa.	Teaching	A. C. Ackenheil	3	1,200	Std. properties, consolidation, triaxial shear	Harvard & Michigan Manuals	None
Princeton Univ.	Princeton, N. J.	Teaching, research, & advisory	Prof. G. P. Tschebotarioff & Dr. H. F. Winterkorn	10	16,050	Std. properties, consolidation(8), direct (3), triaxial shear(1) unconfined compression(1)	ASTM, AASHO, & others	Soil stabilization, soil vibration, earth pressures
Purdue Univ.	Lafayette, Ind.	Teaching & research	Prof. R. E. Fadum	13	3,700	Std. properties, consolidation, triaxial shear	ASTM, AASHO, CBR "Notes on Soil Testing" Harvard	Aerial photography studies of soil types and land forms
Rensselaer Polytechnic Institute	Troy, N. Y.	Teaching & research	Prof. E. J. Kilcawley	8	2,125	Std. properties, consolidation, direct & triaxial shear	ASTM, CBR	Chemical & electrical soil stabilization
Rose Polytechnic Institute	Terre Haute, Ind.	Teaching	E. A. McLean	1	648	Std. properties & triaxial shear	AASHO, Proctor, CBR	None
Rutgers Univ.	New Brunswick, N. J.	Teaching & research	Prof. F. C. Rogers	10 to 15	4,000	Std. properties, consolidation, direct & triaxial shear	ASTM, AASHO, CBR	None
Univ. of Santa Clara	Santa Clara, Calif.	Teaching & advisory	Prof. W. R. Hogue	1	800	Std. properties	ASTM, AASHO	None
Univ. of S. C.	Columbia, S.C.	Teaching	Prof. E. M. Henderson	1	600	Std. properties	ASTM	Soil stabilization
Southern Methodist Univ.	Dallas, Texas	Teaching & advisory	Sophus Thompson	2	500	Std. properties, consolidation	AASHO	None
Stanford Univ.	Stanford Univ., Calif.	Teaching & research	Prof. H. A. Williams	1	150	Std. properties, consolidation, direct & triaxial shear	(Not known)	(Not known)
Univ. of Tenn.	Knoxville, Tenn.	Teaching	Prof. A. T. Granger	2	600	Std. properties, consolidation, direct shear	ASTM	None
Texas Technological College	Lubbock, Texas	Teaching	J. H. Murdough	7	700	Std. properties	(Not known)	Soil stabilization
Texas College of A&M	College Station Texas	Teaching & research	Prof. S. J. Buchanan	4	515	Std. properties, consolidation, triaxial shear	"Notes on Soil Testing" Harvard	None
Univ. of Texas	Austin, Texas	Teaching & research	Prof. R. F. Dawson	3	3,480	Std. properties, consolidation(26), direct(2), & triaxial (3) shear	ASTM, Harvard notes	Consolidometer improvements
Tulane Univ.	New Orleans, La.	Teaching & consulting	J. K. Mayer	3	412	Std. properties, consolidation(2), direct shear(1)	(Not known)	(Not known)
Union College	Schenectady, N. Y.	Teaching	H. G. Harlow	1	1,125	Std. properties, triaxial shear	"Notes on Soil Testing" Harvard	None
Utah State Agri. College	Logan, Utah	Teaching & research	Dr. D. F. Peterson	1	1,400	Std. properties, consolidation, direct & triaxial shear	ASTM	None

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA[1]

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment[2]	Standard	Specialized or new developments
Univ. of Utah	Salt Lake City, Utah	Teaching & research	Prof. R. L. Sloane	2	1,050	Std. properties, consolidation(2), direct (1) & triaxial (1) shear	ASTM, Housel , CBR	None
Vanderbilt Univ.	Nashville, Tenn.	Teaching	Prof. W. H. Rowan	1	900	Std. properties, consolidation, direct shear	ASTM	None
Virginia Military Institute	Lexington, Va.	Teaching	Maj. W. B. Wilson	2	2,400	Std. properties	ASTM, AASHO, CBR	(Not known)
Univ. of Virginia	Charlottesville Va.	Teaching & research	Prof. R. E. L. Gildea	1	2,000	Std. properties	ASTM, CBR	None
Wash. Univ.	St. Louis, Mo.	Teaching	H. G. Poertner	1	900	Std. properties, consolidation, direct & triaxial shear	ASTM	None
Univ. of Wash.	Seattle, Wash.	Teaching & research	Prof. R. G. Hennes	3	1,344	Std. properties, consolidation(8), direct (5) & triaxial(2) shear	(Not known)	None
W. Va. Univ.	Morgantown, W. Va.	Teaching	R. P. Davis	2	-	Std. properties, consolidation, triaxial shear	(Not known)	(Not known)
Univ. of Wis.	Madison, Wis.	Teaching, & research, & consulting	G. W. Washa	3	1,000	Std. properties, consolidation, triaxial shear	ASTM, CBR, Burmister Triaxial by Watson	(Not known)
Worcester Polytechnic Institute	Worcester, Mass.	Teaching	Prof. W. F. M. Longwell	2	-	Std. properties, consolidation	AASHO	None
Univ. of Wyoming	Laramie, Wyo.	Teaching	Prof. J. H. Zoller	1	1,500	Std. properties, consolidation	ASTM, AASHO, CBR	(Not known)
Yale Univ.	New Haven, Conn.	Teaching, research, & advisory	D. P. Krynine	1	1,600	Std. properties, consolidation, direct & triaxial shear	ASTM, AASHO	Capillary phenomena
STATE HIGHWAY DEPARTMENTS:								
Alabama	Montgomery, Ala.	Advisory	J. L. Land	Variable	3,000	Std. properties	ASTM, AASHO	None
Arizona	Phoenix, Ariz.	Research, advisory	H. H. Brown	26	1,930	Std. properties	AASHO, CBR	None
Arkansas	Little Rock, Arkansas	Design & construction	E. L. Weles	7	-	Std. properties	AASHO	None
California	Sacramento, Calif.	Advisory	T. E. Stanton	20	5,000	Std. properties	AASHO, ASTM, CBR	(Not known)
Colorado	Denver, Colo.	Testing, research & advisory	V. E. Raukohl	10	1,116	Std. properties	AASHO, CBR, HRB	None
Connecticut	Hartford. Conn.	Design, construction & research	Philip Keene	4	450	Std. properties, consolidation, direct shear	"Notes on Soil Testing" Harvard	Filter apparatus for designs on drainage.

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA1/

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment2/	Standard	Specialized or new developments
Delaware	Dover, Del.	Inspection, testing, investigation	F. J. Bowery	9	2,275	Standard properties	AASHO, ASTM	None
Florida	Gainesville, Fla.	Design, & control	H. C. Weathers	32	8,600	Standard properties	AASHO, ASTM	Fla. soil bearing test
Georgia	Atlanta, Ga.	Advisory	W. F. Abercrombie	13	2,500	Standard properties	AASHO	Soil manual for special tests
Idaho	Boise, Idaho	Testing & advisory	J. Reid	3 to 5	400	Standard properties	AASHO	None
Illinois	Springfield, Ill.	Testing & advisory	H. W. Russel	37	3,270	Standard properties, consolidation, shear	AASHO, ASTM	None
Indiana	Indianapolis, Ind.	Design & construction	J. H. Laver	10	1,000	Standard properties	AASHO, ASTM	Soil-cement stabilization
Iowa	Ames, Iowa	Design & control	Bert Meyers	22	750	Standard properties, consolidation, triaxial shear	AASHO	Rapid soil dryer, mechanical pulverizer, soil displacement apparatus
Kansas	Topeka, Kans.	Research, design, control	R. D. Finney	20 to 30	3,000	Standard properties, consolidation, triaxial shear	ASTM	Triaxial
Louisiana	Baton Rouge, La.	Advisory	L. W. Hough	26	3,700	Standard properties, soil stabilization	ASTM, AASHO	None
Maryland	Baltimore, Md.	Testing & advisory	J. E. Wood	8	-	Standard properties	ASTM, Proctor	Hubbard Field & Florida Bearing
Massachusetts	Boston, Mass.	Advisory	A. V. Bratt	2	2,160	Standard properties	ASTM, AASHO, PRA, CBR	None
Minnesota	St. Paul, Minn.	Research, & control	J. W. Swanberg	(Variable)	630	Standard properties	AASHO, PRA, CBR	Field bearing
Missouri	Jefferson City, Mo.	Testing, research & consulting	R. C. Schappler	10	21,500	Standard properties, soil stabilization punch & triaxial shear	AASHO, ASTM	None
Nevada	Carson City, Nev.	Testing & construction	W. T. Holcomb	10	-	Standard properties	Highway Research Board	None
New Hampshire	Concord, N. H.	Testing, & construction	P. S. Otis	2	-	Standard properties	AASHO	None
New Jersey	Trenton, N. J.	Testing & construction	A. C. Ely	34	2,400	Standard properties, consolidation(3), triaxial shear	AASHO, ASTM	None
New Mexico	Albuquerque, N. Mex.	Testing & construction	E. B. Bail	26	2,300	Standard properties, consolidation, triaxial shear	"Notes on Soil Testing" Harvard	None
New York	Albany, N. Y.	Testing, control and research	E. F. Bennutt	49	6,000	Standard properties, consolidation(7), direct(2) & triaxial shear	ASTM, AASHO	None
North Carolina	Raleigh, N. C.	Testing, construction	L. D. Hicks	17	3,600	Std. properties, consolidation, direct shear, soil stabilization	AASHO, ASTM	None
North Dákota	Bismark, N. Dak.	Testing, research design construction	W. A. Wise	8	600	Std. properties	AASHO, PRA	North Dakota method of soil numbers

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES—LABORATORIES OF THE UNITED STATES OF AMERICA[1]

Institution			Staff		Laboratory Facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment[2]	Standard	Specialized or new developments
Ohio	Columbus, Ohio	Testing, research design, construction	R. R. Litehiser	18	1,950	Std. properties, consolidation, direct & triaxial shear	ASTM, AASHO	None
Oregon	Salem, Oregon	Research, advisory	R. H. Baldock	2	1,260	Std. properties, consolidation, triaxial shear	PRA	(Not known)
Pennsylvania	Harrisburg. Pa.	Testing & supervisory	W. H. Herman	17	Adequate	Std. properties	ASTM, AASHO	None
South Carolina	Columbia, S. C.	Testing & research	S. N. Pearman	8	600	Std. properties	Not known	None
South Dakota	Pierre, S. Dak	Research, advisory	A. W. Potter	6	1,440	Std. properties	AASHO	None
Tennessee	Nashville, Tenn.	Testing	O. W. Hovis	6	400	Std. properties	AASHO	None
Utah	Salt Lake City Utah	Advisory	D. F. Larsen	2	300	Std. properties	AASHO, CBR	None
Virginia	Richmond, Va.	Testing, control, & research	A. B. Cornthwaite	8	1,100	Std. properties	AASHO, ASTM	None
Washington	Olympia, Wash.	Advisory, control, & research	B. Tremper	6	1,300	Std. properties, consolidation, triaxial shear	CBR	None
Wisconsin	Madison, Wis.	Advisory	A. T. Bleck	4	-	Std. properties	CBR	None
Wyoming	Cheyenne, Wyo.	Testing, design	I. E. Russell	7	900	Std. properties	AASHO, CBR	None
UNITED STATES GOVERNMENT AGENCIES:								
Bureau of Reclamation[3]	Denver, Colo.	Testing, research, & construction	R. F. Blanks & W. G. Holtz	20	12,000	Std. properties, consolidation, triaxial shear, soil stabilization	ASTM, USBR	Shear, pore pressure, soil stabilization, vibratory compaction
Bureau of Yards & Docks	Washington, D. C.	Testing, research	L. A. Palmer	4	1,200	Std. properties, consolidation, direct & triaxial shear	AASHO	None
Corps. of Eng.:[4] Waterways Experiment Station	Vicksburg, Miss.	Testing, research, design, control	Lt. Col. R. D. King, J. B. Tiffany, & W. J. Turnbull	-	-	Std. properties, consolidation, direct & triaxial shear	(Not known)	(Not known)
Ohio River Div. Laboratories	Cincinnati, Ohio	Testing, research, design, control	R. R. Philippe F. M. Mellinger	-	-	Std. properties, consolidation, direct & triaxial shear	(Not known)	Photoelastic studies of pressure distribution in soil
District of Columbia	Washington, D. C.	Advisory, design, construction	H. F. Clemmer	6	Adequate	Std. properties, consolidation, shear	AASHO, ASTM	None

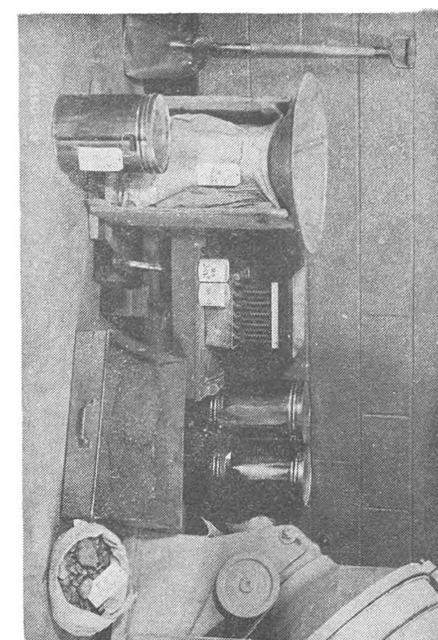
EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA[1]

Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space(sq ft)	Equipment[2]	Standard	Specialized or new developments
Forest Service	Washington, D. C.	Advisory, design, & construction	C. A. Betts	-	-	Std. properties	(Not known)	(Not known)
Panama Canal	Diablo Heights C. Z.	Testing & design	Col. J. H. Stratton	Variable	2,800	Std. properties, consolidation, direct & triaxial shear(4)	"Notes on Soil Testing" Harvard	None
Public Roads Administration	Washington, D. C.	Research & advisory	E. F. Kelley & Harold Allen	14	10,000	Std. properties, consolidation, direct & triaxial shear	AASHO, ASTM	None
Soil Conservation Service	Washington, D. C.	Testing & research	J. C. Dykes	-	-	Std. properties, shear	(Not known)	(Not known)
Territorial Highway Department	Honolulu, T.H.	Testing & research	K. B. Hirashima	3	500	Std. properties, consolidation, direct shear	AASHO, ASTM	None
MISCELLANEOUS AGENCIES:								
American Bitumuls Co.	San Francisco, Calif.	Research, control	P. E. McCoy	20	-	Std. properties	(Not known)	(Not known)
Board of Water Supply of the City of New York	Lackawack, N. Y.		C. F. Heiselman	8	3,000	Std. properties, consolidation, direct shear	"Notes on Soil Testing" Harvard	(Not known)
Department of Water & Power, City of Los Angeles	Los Angeles, Calif.	Design, control, & construction	E. B. Mayer	3	6,000	Std. properties, consolidation, shear	Proctor	(Not known)
Dames & Moore	Los Angeles, Calif.	Consulting	Trent R. Dames	47	5,200	Std. properties, consolidation(7), direct shear(2)	AASHO, Proctor	Shear development
Abbot A. Hanks, Inc.	San Francisco, Calif.	Testing, research & consulting	A. A. Hanks	32	22,000	Std. properties	(Not known)	(Not known)
Hercules Experiment Station	Wilmington, Del.	Research	O. R. Tyler	1	-	Std. properties	(Not known)	(Not known)
Knappen Engineering Co.	New York, N.Y.	Consulting	John Lowe, III	3	110	Std. properties	(Not known)	(Not known)
Koppers Co., Inc.	Pittsburgh, Pa.	Advisory	P. F. Phelan	3	1,000	Std. properties	(Not known)	(Not known)
Charles H. Lee	San Francisco, Calif.	Consulting	C. H. Lee	3	400	Std. properties, consolidation	ASTM	None
Los Angeles County Flood Control Dist.	Los Angeles, Calif.	Testing	P. Baumen	4	3,000	Std. properties, direct & triaxial shear	ASTM, Proctor, BPR, CBR	None
Metcalf & Eddy	Boston, Mass.	Advisory	F. A. Marston	2	-	Std. properties	"Notes on Soil Testing" Harvard	None
Moran, Proctor, Freeman, & Mueser	New York, N.Y.	Research & advisory	J. D. Parsons	20 to 30	4,000	Std. properties, consolidation, direct & triaxial shear	"Notes on Soil Testing" Harvard	None
Mexican Petroleum Corp.	Baltimore, Md.	Research	C. M. Hewett	3	484	Std. properties	ASTM	None
Municipal Testing Lab.	St. Louis, Mo.	Testing & control	J. M. Wendling	2	Adequate	Std. properties	ASTM, AASHO	None

EARTH MATERIALS TESTING FOR ENGINEERING PURPOSES--LABORATORIES OF THE UNITED STATES OF AMERICA1/ — Sheet 9 of 9

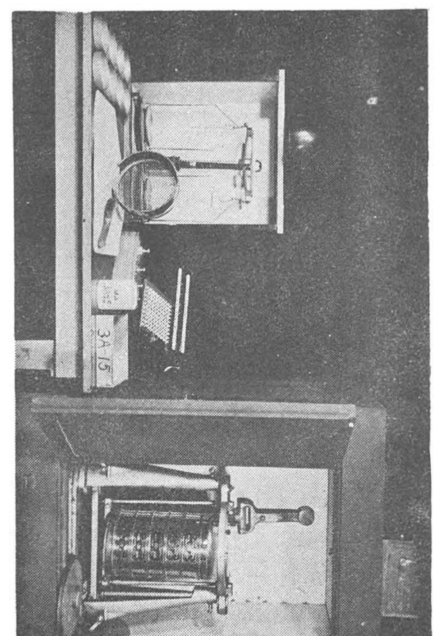
Institution			Staff		Laboratory facilities		Procedures and techniques	
Name	Location	Purpose	Head	No. personnel	Building space (sq ft)	Equipment2/	Standard	Specialized or new developments
Portland Cement Assoc.	Chicago, Ill.	Testing, research	M. D. Catton	5	1,000	Std. properties, soil stabilization	ASTM, AASHO	Soil-cement research
Shell Development Co.	Emeryville, Calif.	Research	V. A. Endersby	8	900	Std. properties, triaxial shear	(Not known)	Stabilization with Pet. Prod.
Twin City Testing & Engineering Lab.	St. Paul, Minn.	Testing, inspection	C. W. Britzius	8	4,050	Std. properties, consolidation, shear	ASTM, AASHO	None
The Thompson & Lichtner Co., Inc.	Brookline, Mass.	Testing, design construction consulting	M. N. Clair	50	20,000	Std. properties, consolidation	ASTM, BPR	None
Soil Testing Services	Evanston Ill.	Testing, research	Th. W. Vanzelst	5	800	Std. properties, consolidation, unc. compression. permeability	(Not known)	Portable unc. compression, app.

1/ Based on data obtained from questionaire submitted to all laboratories on September 10, 1947.
2/ Standard properties testing equipment usually includes apparatus for tests on gradation, Atterberg constants, compaction, specific gravity, permeability, CBR, etc.
3/ Central laboratory, other field laboratories for construction and control purposes located at each active project throughout the Western United States.
4/ Other Corps. of Engineer laboratories are located at the various division and district offices and on each active project throughout the United States.



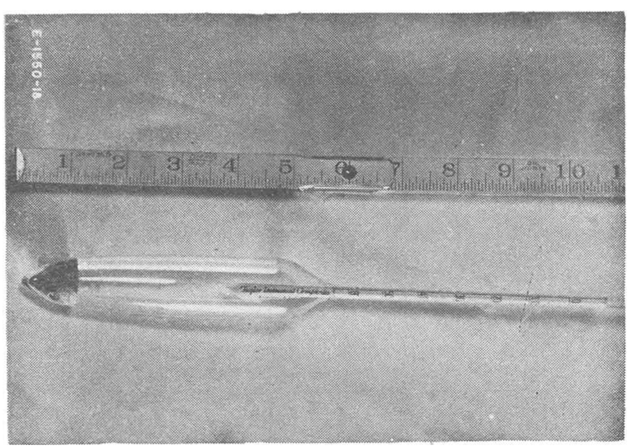
Mechanical Analysis - Coarse Screen

FIG. 1



Mechanical Analysis - Fine Screens

FIG. 2



Mechanical Analysis - Bouyoucas Hydrometer

FIG 3

3) The soil and water passing the No. 200 screen is set aside and allowed to settle. After decanting the clear liquid, the sample is dried. A portion of the dry soil is weighed for the hydrometer analysis, a deflocculating agent (sodium silicate, Acacia solution, etc.) is added, and time allowed for breaking down the soil clusters.

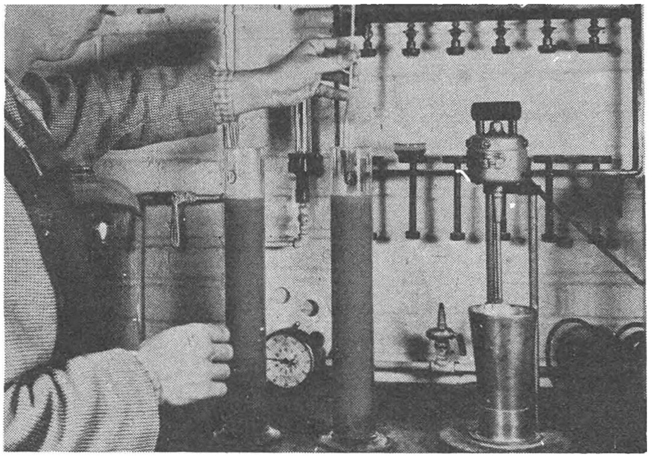
4) The mixture is throroughly dispersed in the cup by means of the mixer for a period of from 2 to 10 minutes and then poured into the 1,000-milliliter graduate. Water is added to fill the graduate which is then inverted repeatedly to mix the additional water and soil. The graduate is then set upright and the hydrometer is inserted. Hydrometer readings are taken at convenient time intervals to determine desired particle size distributions.

5) Appropriate hydrometer corrections are made and the hydrometer readings are converted to particle sizes.

6) The three portions of the mechanical analysis, rock sizes, sand sizes, and hydrometer analysis are combined to give the gradation of the entire sample. This gradation is plotted on semilogarithmic paper with percent larger than (or smaller than) as ordinates on the arithmetic scale and the particle sizes as abscissas on the logarithmic scale (see Figure 5).

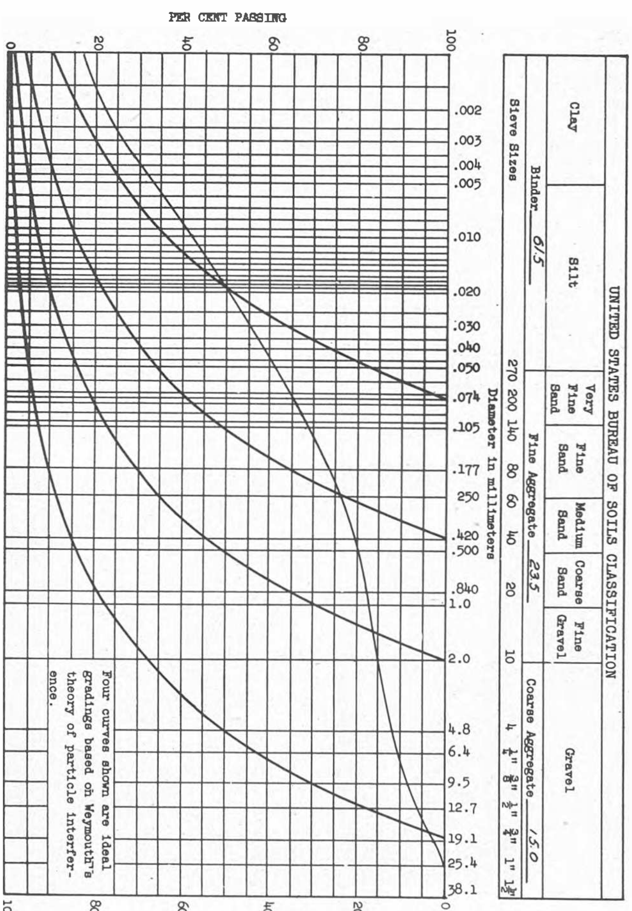
Corrections applied to the hydrometers are for temperature and specific gravities other than that for which the hydrometer was calibrated, correction of meniscus reading, and also a correction for the change in specific gravity of the water due to the addition of the deflocculating agent. The above procedure is similar to that used by the New York Board of Water Supply, the University of Maine, and the Bureau of Reclamation.

A mechanical analysis of soils by elutriation is made by the Georgia State Highway Department. A portion of the material passing the No. 10 sieve is dried, weighed, defloccu-



Mechanical Analysis - Dispersion Apparatus

FIG. 4



MECHANICAL ANALYSIS

(Reference--Methods ST-4, ST-34, ST-10)

Project *Toledo Water Dept.* Lab. Sample No. *38-H-82*

Location *Toledo Ohio* Field Sample No. *H-1-6*

Tested by *R. Gubbins* Date *11-15-38* Checked by *J.J. Demmo* Date *11-16-38*

Sieve Analysis of Material Retained on No. *10* Sieve (W_1)

Sieve Number	Retained Weight of W_1	Retained Per Cent of W_1	Retained Per Cent of W	Cumulative Per Cent of W: Retained	Cumulative Per Cent of W: Passing
	g.	%	%	%	%
1-1/2"	0	0	0	0	100.0
1"	0	0	0	0	100.0
3/4"	30.0	10.0	1.5	1.5	98.5
3/8"	70.2	23.4	3.5	5.0	95.0
#4	79.8	26.6	4.0	9.0	91.0
#10	120.0	40.0	6.0	15.0	85.0
#40					
#200					
Pass 200					
Total	300.0	100.0	15.0		

Sieve Analysis from Material from Hydrometer Analysis (W_3)

Sieve Number	Particle Size	Retained Weight	Retained Per Cent of W_3	Retained Per Cent of W	Cumulative Per Cent of W: Retained	Cumulative Per Cent of W: Passing
	mm.	g.	%	%		
10	2.0	0	0	0	15.0	85.0
20	0.840	1.5	3	2.5	17.5	82.5
40	0.420	1.5	3	2.5	20.0	80.0
60	0.250	2.5	5	4.2	24.2	75.8
140	0.100	4.5	9	7.6	31.8	68.2
200	0.074	2.5	5	4.2	36.0	64.0
Pass	#200	37.5	75	64.0	100.0	0
	Total	50.0	100	85.0		

Original Sample W = *2000* g. 100%

Partial Sample W_1 = *300* g. *15* %

Partial Sample W_2 = *1700* g. *85* %

Hydrometer Analysis of Material Passing No. *10* Sieve (W_2).

Specific Gravity

(Reference--Methods ST-5, ST-6, ST-9)

Wt. of dry soil and flask W_1 = *80.882* g. Volume of soil V_s = *11.3* cc.

Wt. of flask No. *330* W_2 = *50.671* g. App. Sp. Gr. ($G_A = W_o \div V_s$ = *2.68*

Wt. of dry soil $W_1 - W_2 = W_o$ = *30.211* g. (S_T - 9E G_A =

Specific Gravity Correction a = *.99*

Hydrometer No. *170140* Weight of Sample W_3 = *50.0* g.

Time	Time Min.	Temp. °C.	Hydrometer Read: Orig.	Hydrometer Read: ΔR	Hydrometer Read: R	% Pass 100 Ra ÷ W_3	Corr. Coeff. K_L	Corr. Coeff. K_G	Corr. Coeff. K_T	Diameter mm.	Corrected Diameter	% Pass of W
8:01	1	22.5	32.7	.10	32.8	65.0	.507	.99	.96	.078	.038	55
8:02	2	22.5	31.2	.10	31.3	62.0	.510	.99	.96	.055	.027	[illegible]
8:05	5	22.5	28.1	.10	28.2	55.9	.516	.99	.96	.035	.017	48
8:10	10	22.5	26.0	.10	26.1	51.7	.520	.99	.96	.025	.012	44
8:15	15	22.5	24.8	.10	24.9	49.3	[illegible]	.99	.96	.020	.010	42
8:30	30	22.5	22.5	.10	22.6	44.7	.527	.99	.96	.014	.007	38
9:00	60	22.5	19.2	.10	19.3	38.2	.532	.99	.96	.010	.005	32
10:00	120	22.5	16.5	.10	16.6	32.9	.538	.99	.96	.007	.0036	[illegible]
8:00	1440	22.5	10.0	.10	10.1	20.0	.553	.99	.96	.002	.001	17

NOTE. Percentages of W_3 also apply directly to W_2, the material passing the lowest sieve. These percentages as well as those recorded in Column 7, (100 Ra ÷ W_3), of the hydrometer analysis are converted to percentages of the total sample W by multiplying the ratio of the partial sample W_2 to the total sample W

Mechanical Analysis - Data and Curve Sheets

FIG. 5

lated, and dispersed in water. This mixture is allowed to settle for 8 minutes and then the supernatant liquid is siphoned off. The residue is again dispersed in more water and allowed to settle 8 minutes and again siphoned. This process is repeated until the siphoned water is clear. The soil contained in the siphoned water is clay and the residue is screened on a nest of sieves from a No. 20 to a No. 200, thus separating the sand and silt sizes. Elutriation is also used at the University of Michigan.

At the University of Notre Dame the sample of soil matrix is wet sieved through the nest of screens, and the material passing the No. 200 screen is analyzed using a specific gravity type hydrometer.

The Universities of Michigan, Harvard, Columbia, Maine, and Utah, and Texas A&M College make a hydrometer analysis on the entire soil matrix after which the material is washed on a No. 200 sieve and that fraction retained on the sieve is dried and screened through a nest of United States Standard sieves. This procedure is similar to that prescribed by the A.S.T.M. Standard, Designation D 422-39.

Binocular microscopes are available at the California Institute of Technology, the University of Michigan, and the Bureau of Reclamation for examination of the shapes of the soil particles.

Refinements and detailed procedures for the mechanical analysis tests are given in the following publications: Notes on Soil Testing for Engineering Purposes--Harvard University; Laboratory Manual of Soil Testing Procedures--University of Michigan; Laboratory Procedures in Testing Earth Materials for Foundation and Construction Purposes--Bureau of Reclamation; Procedures for Testing Soils--American Society for Testing Materials; Methods of Sampling and Testing--The American Association of State Highway Officials.

C. SPECIFIC GRAVITY

1. General

The specific gravity of a material is defined as the ratio of the weight of the dry material to the weight of an equal volume of water at 4° C. The specific gravity is determined by direct displacement or direct displacement after evacuation of entrapped air.

All laboratories reported having apparatus for determining the specific gravity, consisting of flasks, pycnometers, balances, etc.

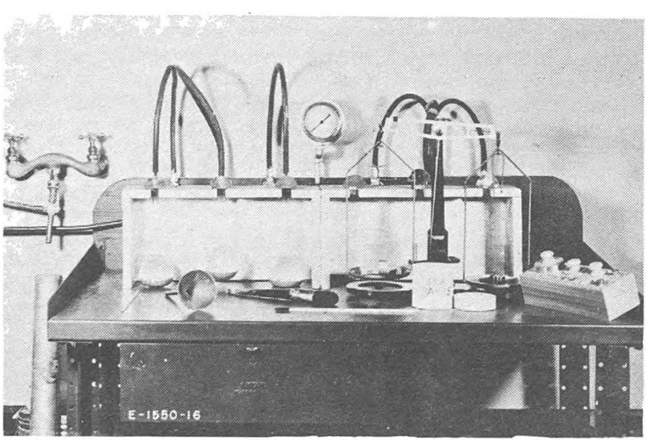
2. Test Procedure for Coarse Materials

The specific gravity of the rock and gravel fraction can be determined by direct displacement of water. This fraction is usually obtained by separation on a No. 4 or 1/4-inch screen, although other size separations are frequently used. Individual rocks or mixtures are weighed in air and weighed again in water (completely submerged). A wire basket suspended in water from the scale is a suitable container for weighing in water. The difference between the weight in air and weight in water is converted to the volume of the sample. The specific gravity in the centimeter-gram system is equal to the weight in air divided by the volume. A can equipped with an overflow device can also be used for coarse material. After the sample is weighed in air, it is placed in the can and the displaced water is caught and measured from the overflow. Coarse materials are normally handled in a saturated, surface dry condition; that is, the material is soaked in water then surface dried with a towel before determining the specific gravity. Corrections are made for the density of water at temperatures other than 4° C.

3. Test Procedure for Fine Materials

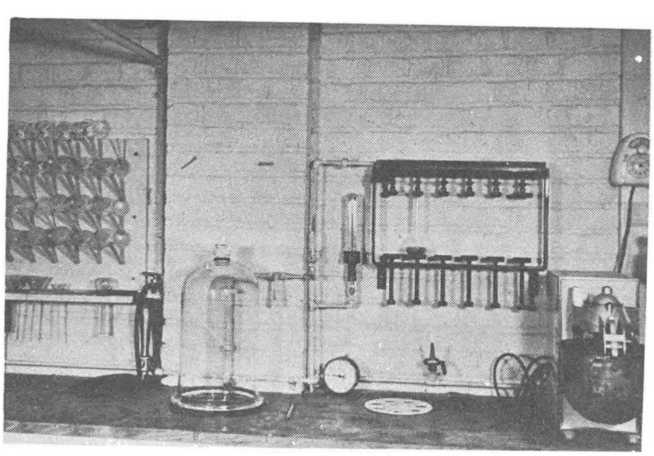
A calibrated volume flask is used for determining the specific gravity of the soil fraction, that is, the material smaller than the coarse sizes discussed above. The weight of the flask filled with water to the calibration mark is determined. An oven-dried portion of the soil is placed in water in the flask, and the entrapped air is removed by an evacuator. The flask is then filled with water to the calibration mark and further evacuated if necessary. The volume of the soil is equal to the calibrated weight of the flask and water plus the weight of the soil used minus the combined weight of the flask, soil, and water after evacuation. The specific gravity in the metric system is equal to the weight of the soil divided by the volume of the soil. Flasks are calibrated for a specific temperature or temperature range, and corrections to 4° C are made. Pycnometer jars may be substituted for the flasks discussed above. Figures 6 and 7, respectively, are the specific gravity setups at the Bureau of Reclamation and the Bureau of Yards and Docks.

Detailed procedures for determining the specific gravities of soils are given in Proce-



Specific Gravity - Flasks and Aspirator

FIG. 6



Specific Gravity - Flasks and Aspirator

FIG. 7

dures for Testing Soils-- American Society for Testing Materials; Methods of Testing and Sampling--The American Association of State Highway Officials; Laboratory Procedure in Testing Earth Materials for Foundation and Construction Purposes--Bureau of Reclamation; Notes on Soil Testing for Engineering Purposes--Harvard University; and Laboratory Manual of Soil Testing Procedures--University of Michigan.

D. MOISTURE LIMIT TESTS

1. General

The most noticeable physical property of a true clay is its plasticity. Plasticity is the property of a fine-grained soil which allows it to be kneaded into putty-like consistency when properly moistened. Any soil that can be readily rolled into a thread without crumbling is considered to be plastic.

A series of relative plasticity tests, devised by A. Atterberg, have been in use for about 30 years. These tests have been modified, and correlated with behavior, for highway work by the Bureau of Public Roads. In general, these tests, which are often referred to as limits of consistency or Atterberg tests, indicate the effects of variations in moisture on the nature (plasticity) of the soil when it is manipulated in accordance with an established standard procedure. The coefficients or constants determined are "liquid limit", "plastic limit", "plasticity index", and "shrinkage limit". Two other tests, the "centrifuge moisture equivalent" and "field moisture equivalent" tests, are used to indicate the water holding capacity of a soil. These constants are expressed as numbers which are percentages of moisture by dry weight of soil.

As a very wet, fine-grained soil dries out, it passes progressively through different stages of consistency from a liquid to a solid state. In a very wet condition, the mass will act like a viscous liquid and is referred to as the liquid state. With drying, the mass becomes stiffer and gradually loses its capacity to flow as a liquid and can be easily molded and holds its shape. This is referred to as the plastic state. Upon further drying, the plastic properties are reduced to the extent that the mass becomes a semisolid; that is, it can still be deformed in a plastic manner, but considerable force will be required. This condition is referred to as the semisolid state. With still further drying, the mass will shrink and become extremely hard, and the shrinkage will continue until it reaches a limiting volume. This condition is referred to as the solid state.

The Atterberg limits are defined as the transition points between the general stages of consistency as follows:

Stage of Consistency	Limits between Stages
Liquid	
	Liquid limit
Plastic	
	Plastic limit
Semisolid	
	Shrinkage limit
Solid	

The liquid limit is that moisture content which will cause the soil particles to separate to such an extent that the soil mass will act as a very weak plastic, and any additional water will cause the mass to act as a viscous liquid. The test determines the moisture content that will cause a groove in the soil mass to close under a standard method of manipulation.

The plastic limit is that moisture content which will not separate the soil particles and will create just enough surface tension to give contact pressures between the soil grains and thus cause the soil mass to act as a weak semisolid mass. The test determines the minimum moisture content at which soil can be rolled into threads 1/8 inch in diameter without the threads breaking into pieces.

The plasticity index is the difference between the liquid and plastic limit, and represents the range of moisture through which a soil will be plastic. Clays have a large plasticity index. Silts have a small plasticity index. Therefore, the index is a measure of the clayey properties.

The shrinkage limit is the moisture content at which a reduction in moisture will not cause a decrease in the volume of the soil mass, but at which an increase in the moisture content will cause an increase in the volume of the soil mass. At the shrinkage limit the soil mass will be solid. The test procedure is to measure the volume of a dried soil pat and compute the moisture content for complete saturation based on the specific gravity of the soil particles and the density of the dried pat.

The centrifuge moisture equivalent of a soil is the amount of moisture retained by the soil which has been first saturated with water and then subjected to a force equal to 1,000 times the force of gravity for 1 hour.

The field moisture equivalent of a soil is the minimum moisture content at which a drop of water placed on a smoothed surface of the soil will not immediately be absorbed by the soil but will spread out over the surface and give it a shiny appearance.

2. Test Procedure

All of these tests are made on that portion of the soil that will pass a No. 40 sieve, United States Standard sieve series or No. 35 sieve on the Tyler series, with a sieve opening of 0.42 millimeter. Figures 8 and 9 show the procedure and apparatus for some of the moisture limit tests.

Detailed procedures for conducting these tests are included in: Procedures for Testing Soils--American Society for Testing Materials, and Methods of Sampling and Testing--The American Association of State Highway Officials.

E. COMPACTION AND PENETRATION RESISTANCE

1. General

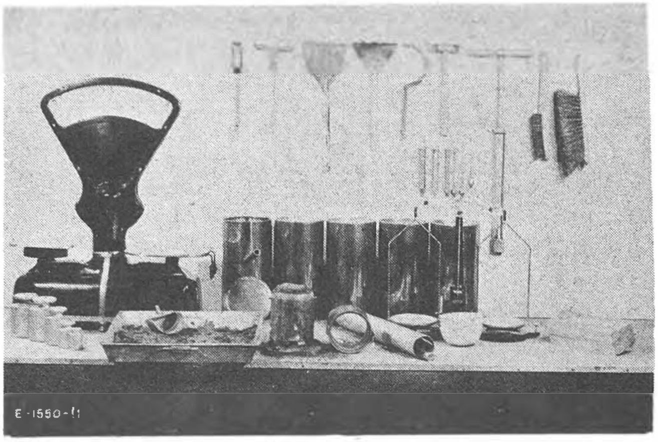
These tests consist of the compaction, by established or special procedure, of a soil sample into a cylinder or container of known volume for determination of the density obtainable with varying moisture contents and degrees of compaction and for determination of the influence of varying moistures and densities on the firmness of the soil. The data obtained from these tests furnish information that can be used as a guide for establishing moisture and density control for other tests, as unit weight data for design purposes, and for the field control of specific materials to be used in earthfill structures.

The impact method of compaction is the most widely used in the laboratories of the United States. Some laboratories are equipped to conduct compaction tests by static load or vibration methods. Considering the impact method, there are only two generally accepted methods and equipment for the compaction tests--the Modified AASHO Standard and the Proctor Standard. The Standard AASHO and the proposed ASTM Standard are the same as the Standard Proctor.

The Proctor procedure requires that three equal layers of soil be compacted into a standard cylinder of 1/30 cubic foot capacity by

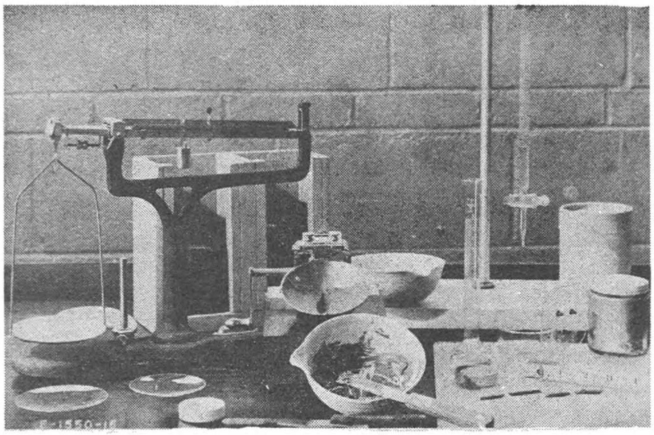
Moisture Limits - Plastic Limit Test

FIG. 8



Compaction - 1/20 Cubic Foot Cylinder and Penetration Resistance Tester

FIG. 10



Moisture Limits - Test Apparatus

FIG. 9

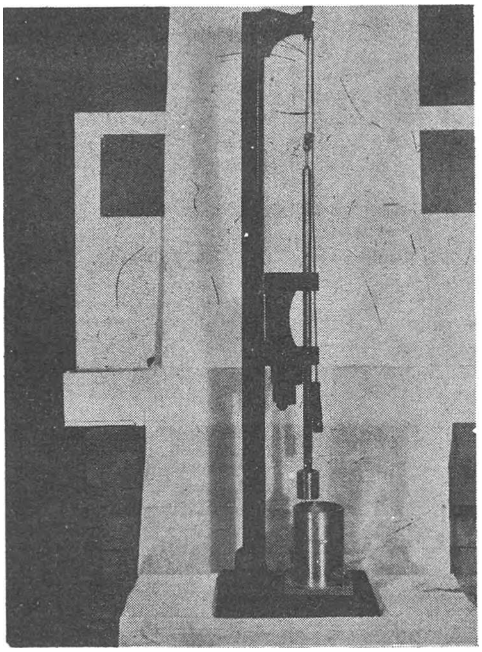
25 blows per layer of a 5.5-pound tamper dropped 12 inches. (The Bureau of Reclamation Standard differs in that a cylinder of 1/20 cubic foot capacity and an 18-inch drop are used, resulting in the same compactive effort per cubic inch of soil.)

The Modified AASHO procedure requires that the soil be compacted into a standard cylinder of 1/30 cubic foot capacity using 25 blows of a 10-pound hammer falling 18 inches on each of five equal layers.

Both types of equipment are available at the laboratories of the University of Notre Dame, Columbia University, the Colorado Highway Department, the California Institute of Technology, and the consulting firm of Dames and Moore.

The Standard Proctor equipment is available at the University of Michigan; Texas A&M College; Purdue University; The New York Board of Water Supply; the Georgia, Ohio, and Minnesota State Highway Departments; the Bureau of Yards and Docks; and the Portland Cement Association.

The penetration resistance test, sometimes performed in connection with the compaction test, is conducted with a calibrated stock and penetrating needles of various end areas. Equipment for this test is shown in Figure 10, along with the compaction equipment



Compaction - Controlled Drop Hammer and Proctor Mold

FIG. 11

used by the Bureau of Reclamation.

A controlled drop hammer and Proctor mold are shown in Figure 11. This equipment is part of that used at the soil laboratory of the Portland Cement Association. Figure 12 shows a mechanically operated compaction apparatus in the Bureau of Reclamation laboratory.

2. Compaction and Penetration Test Procedure
   a. The apparatus for conducting these tests consist of the following:

1) Compaction cylinder. Proctor or AASHO mold of 4-inch diameter and 4.59-inch height, or Bureau tapered mold of 4.28-inch average diameter and 6.0-inch height. Extension collars are provided with both molds.

2) Rammer. A metal rammer having a 2-inch diameter circular face and weighing 5.5 pounds (or 10 pounds). The rammer shall

be equipped with a suitable arrangement to control the specified drop.

3) Hydraulic press or jack for removing the compacted specimen from the mold.

4) Penetration-resistance tester stock and set of needles with varying end areas, from 1/40 to 1 square inch.

5) Scales, ovens, balances, etc.

b. Sample Preparation

Six to fifty pounds of soil passing the No. 4 sieve (1/4-inch, No. 10, or other separation sizes may be used) are moistened, thoroughly mixed, and stored in a container to allow the moisture to permeate the soil. Add sufficient water to cause the soil to adhere together slightly when sqeezed firmly in the palm of the hand.

c. Testing

1) Place the mold on a rigid foundation. Mix 6 to 7 pounds of material in a pan, then compact in the cylinder (with extension attached) in three equal layers, each layer receiving 25 blows from the hammer dropping free from a height of 12 inches above the elevation of each compacted layer (18 inches for 1/20 cubic foot mold). Distribute the blows uniformly over the surface of the layer being compacted. Remove the extension and trim the excess compacted soil to the top of the cylinder, weigh, and record. The weight of the wet soil is divided by the size of the mold in cubic feet to obtain the wet density per cubic foot.

2) If the penetration resistance test is performed, place the mold containing the sample on the worktable or floor and force the needle into the compacted soil at a rate of approximately 1/2 inch per second. When the needle has penetrated to a depth of approximately 3 inches, the reading on the plunger is observed and recorded. The penetration resistance in pounds per square inch is the average of at least three readings divided by the area of the needle.

3) Remove the compacted soil from the cylinder and obtain a moisture sample. Break up the soil specimen and add water in sufficient amounts to increase the moisture content of the soil sample by about 1 to 2 percent and repeat the compaction procedure for each increment of water added. Continue until the soil becomes very wet or there is a substantial decrease in the wet weight of the compacted soil.

4) Determine the dry density of the soil at the various moisture contents and plot as ordinates against moisture content as abscissas and draw a smooth curve through the points. The peak point of the curve determines the maximum dry density and the optimum moisture content for the soil at this compactive effort.

5) Separate soil samples for each compaction point are indicated if the soil particles tend to break down under manipulation.

6) The penetration-resistance, when determined, is plotted as resistance in pounds per square inch as ordinates against moisture contents as abscissas.

7) Figure 13 shows typical compaction data and plot sheets.

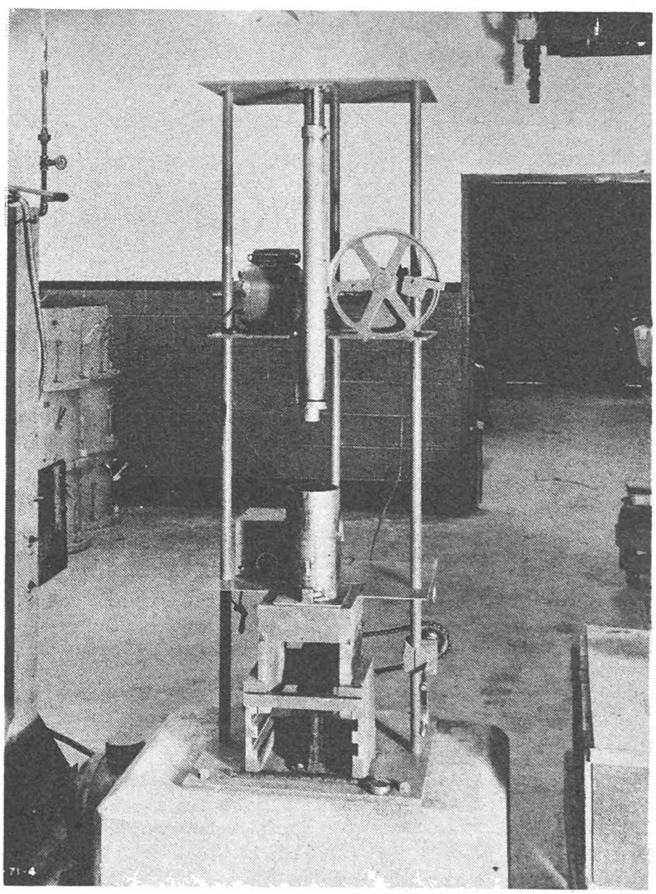
The Modified AASHO Standard is similar to the above procedure except that five layers of soil are compacted by 25 blows per layer of a 10-pound hammer dropped I8 inches. No penetration resistance test is prescribed in this standard. Approximately 4.5 times more compactive effort is expended in the Modified AASHO Standard than in the Proctor Standard.

The compaction tests are conducted on that portion of the total sample passing the No. 4 screen at most laboratories including the Highway Departments of Ohio and Georgia, the Bureau of Reclamation, and the firm of Dames and Moore. The New York Board of Water Supply uses the material passing the 1/4-inch screen and for fine textured soils, the University of Michigan uses the material passing the No. 10 screen.

Compaction of soils by static pressure is accomplished by pressing soils into a cylinder using a plunger having a diameter equal to the diameter of the cylinder. Number of layers, pressures, and time of application of pressures are variables. Density correlations with either Proctor or Modified AASHO Standards are established. The University of Utah is using the static compaction to obtain densities higher than the two standard impact methods. Soils are compressed in the standard mold at various moisture contents and under increasing increments of load of 500 pounds per square inch until an "ultimate" maximum density is determined. Figure 14 shows this test apparatus.

The compaction of coarse free draining material is difficult with the impact method. However, a density-moisture relation can be determined by vibrating the soils. The soil at various moisture contents is vibrated or bounced in a standard mold for a specified period of vibration or number of times.

Detailed procedures for conducting the compaction test are included in: Procedures for Testing Soils—American Society for Testing Materials; Methods of Sampling and



Compaction - Mechanical Compaction Apparatus

FIG. 12

U. S. BUREAU OF RECLAMATION
Earth Materials Laboratory

COMPACTION AND PENETRATION RESISTANCE TESTS

Sample No. ________ Project ________________ Feature ________________

Compacted by ____________ Recorded by ____________ Date ____________

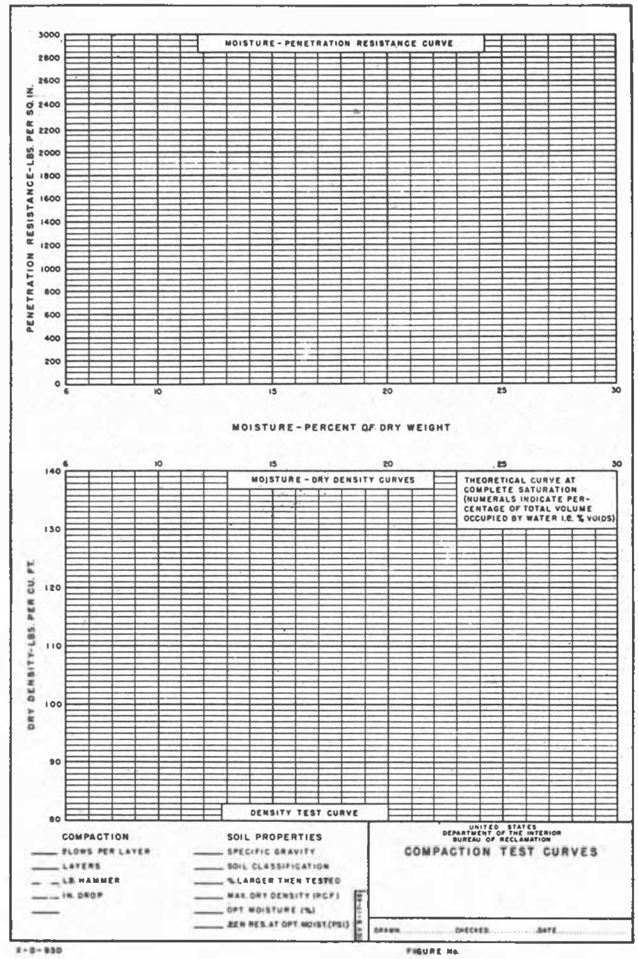
Degree of compaction ________________ Volume of Cylinder 0.05 cu. ft.

Test No.	1	2	3	4	5	6	7	8
Density Determinations								
Water Added - c.c.								
Wt. Cyl. & Wet Earth - lb.								
Wt. of Cylinder - lb.								
Wt. of Wet Earth - lb.								
Wet Density lb./cu.ft.								
Penetration Resistance Determinations								
Needle No.								
Area of Needle - sq. in.								
Average Reading - lb.								
Penet. Resis. lb./sq.in.								
Moisture Determinations								
Dish No.								
Wt. Dish & Wet Soil - g.								
Wt. Dish & Dry Soil - g.								
Weight of Dish - g.								
Weight of Water - g.								
Weight of Dry Soil - g.								
Moist. Cont. % Dry Wt.								
Dry Density lb/cu.ft.								

Computed by ____________ Checked by ____________ Date ____________

QUESTIONS TO ANSWER FROM OBSERVATIONS BY OPERATORS DURING TEST

1. How fast does sample absorb water? Fast ________ Medium ________ Slow ________
2. Is difficulty encountered in mixing water with soil? ________
3. Are penetration needle reading reliable? ________
4. At what test Nos. is sample crumbly? ________ Firm? ________ Soft? ________
5. Was bleeding noticed during test? ________ If so, what test nos.? ________
6. At what test nos. is sample spongy? ________
7. Other comments ________



Compaction - Data and Curve Sheets

FIG. 13

Testing--The American Association of State Highway Officials; Laboratory Manual of Soil Testing Procedures--University of Michigan; Notes on Soil Testing for Engineering Purposes--Harvard University; and Laboratory Procedure in Testing Earth Materials for Foundation and Construction Purposes--Bureau of Reclamation.

F. PERMEABILITY

1. General

The "permeability" or "percolation" tests herein described are conducted to determine the quantity of water under pressure that will pass through materials at various placement conditions. Results of these tests are expressed as a "coefficient of permeability" which is defined as the rate of seepage per unit of area under a hydraulic gradient of one at a water temperature of 20° C. The samples are tested in the undisturbed or recompacted condition as desired to simulate expected field conditions. Two general types of tests are performed depending on the material to be tested, the conditions imposed, and the apparatus available for use. They are (1) the constant head and (2) the variable head permeability tests. The fundamental difference in the two, as the names imply, is in the apparatus setup. The constant head permeameter depends upon keeping the hydraulic gradient constant and measuring the quantity of water passing through the sample in a given time. In the variable head permeameter, the water is fed to the sample from a calibrated standpipe. The drop in water surface is measured over a known interval of time giving the necessary data for computing the quantity of water passing through the sample and also the data for computation of head for that period.

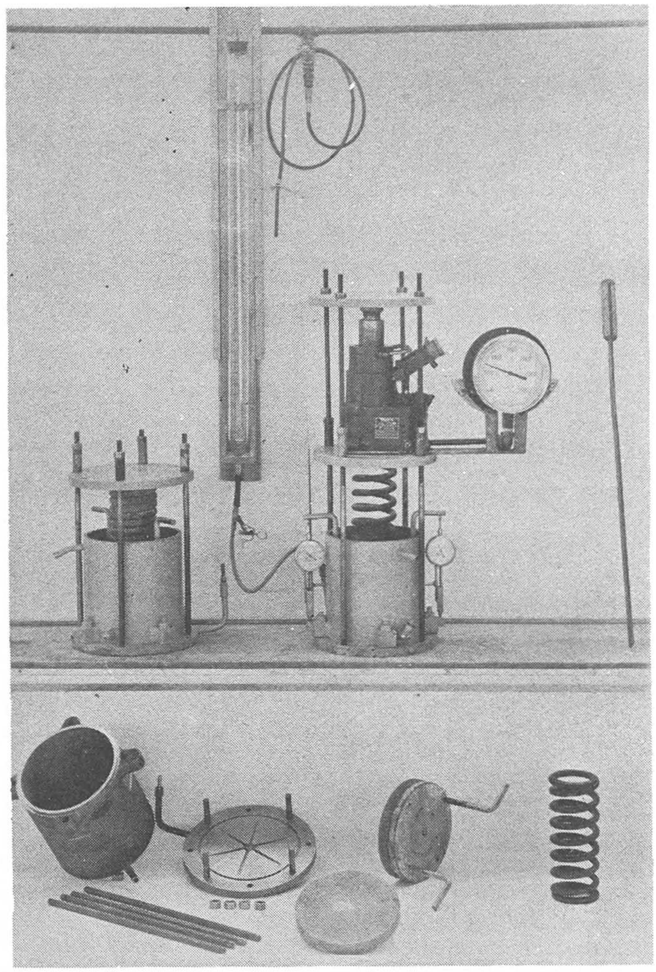
Permeameters used in various laboratories throughout the United States are, in general, of the two types mentioned above. Many laboratories subject the sample to a load to determine the settlement which will occur while saturation takes place in the soil and the effect of settlement on permeability. Some laboratories obtain permeability data in the consolidometer during the consolidation test.

2. Testing Equipment

The Bureau of Reclamation uses the constant head percolation-settlement apparatus for recompacted samples and the variable head standpipe in the consolidometer, for undisturbed foundation samples. The pore pressure-consolidation-permeability test apparatus is used to a large extent for permeability measurements on undisturbed soil cores. (See Section K, Item 9.) Constant pressure head tanks are used to supply water to the soil specimens in this test. Figures 15 and 16, respectively, show the setup for recompacted 8-inch and 20-inch diameter embankment samples. Also shown is the equipment for loading and measuring the movement in the sample. The principle of the Mariotte Flask is used to obtain

Compaction - Static Load Apparatus

FIG.14



Permeability - 8-inch Diameter Container

FIG. 15

a constant head of the magnitude desired. Figure 17 shows a hydraulic machine for loading the sample. The falling head permeameter for the consolidometer is for loading the sample. The falling head permeameter for the consolidometer is shown in Figure 18.

Harvard University has the variable head permeameter for undisturbed and recompacted samples, the constant head apparatus for recompacted samples and a constant head attachment for the consolidometer. A unique device is used to de-air the water for use in permeability tests. The tap water is sprayed and collected in a vacuum, which effectively removes sufficient air from the water to perform the tests without appreciable error.

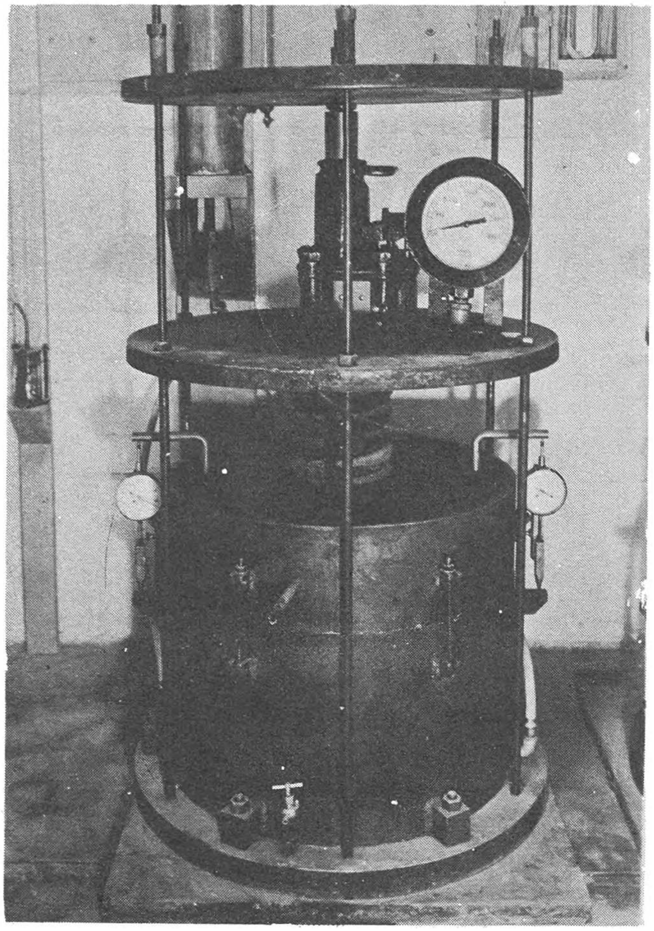
The University of Michigan has the constant head type of permeability apparatus. Undisturbed or recompacted specimens 4.52 inches in diameter are tested in a specially designed permeability cylinder using a calibrated spring for maintaining a selected vertical load or for measuring the vertical pressure required to keep a constant specimen volume. Several tests are performed at various constant heads to determine the relation between the hydraulic gradient and the equivalent velocity. The test data are reduced to equivalent velocity at 20° C for any hydraulic gradient. These variables are plotted for at least three hydraulic gradients. Any intercept at zero velocity is interpreted as the equivalent capillary head which must be overcome before percolation takes place.

The firm of Dames and Moore has a constant head percolation apparatus as shown in Figure 19. The test is performed on core specimens 1 inch in diameter subjected to load so that sample movements may be taken.

Columbia University has three permeability test devices fitted with porous stones at the bottom and a screen with a spring at the top of the specimen for maintaining a constant density, and two water manometer outlets for measuring the loss of head. These devices can be used for either constant head or variable head tests. Water is supplied from a constant head tank with a sand filter bed to remove a large part of the air from the tap water.

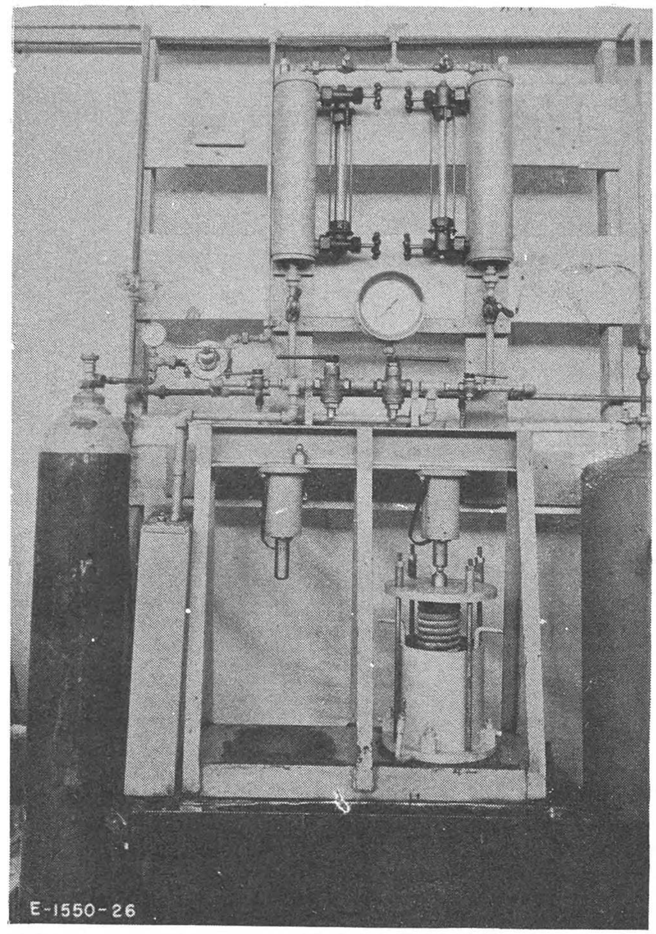
The Ohio Department of Highways uses a very simple variable head permeameter for field and laboratory made up of Proctor molds as shown in Figure 20.

Two methods of determining the permeability are used by the New York Board of Water Supply: 1) The dry soil is packed into 1-1/8- by 7-inch transparent plastic cylinders at average fill density. Pressure from a gas storage tank forces water through the soil and the seepage velocity is determined by measuring the visible line of saturation. Since the velocity is partly due to capillarity, a correction must be applied; (2) The dry soil in a transparent plastic cylinder 6 inches in diameter and 17 inches long. Water is forced upward through the soil with pressure supplied by a gas storage tank and the head along the sample measured by five piezometer tubes connected to mercury manome-



Permeability - 20-inch Diameter Container

FIG. 16



Permeability - Hydraulic Loading Apparatus

FIG. 17

ters. The water used for both methods is previously distilled and de-aired.

Both constant head and variable head permeameters are available at the University of Notre Dame, the California Institute of Technology, Purdue University, and the Connecticut Highway Department.

3. Permeability Test Procedure

a. Apparatus

1) Undisturbed sample preparation equipment, such as cutters and trimmers.

2) Special or standard compaction equipment for the preparation of recompacted samples. A more detailed list can be found in the discussion on compaction (Section E).

3) Permeability cylinder equipped according to the type of permeameter desired and whether the sample is to be loaded during the test for settlement measurements.

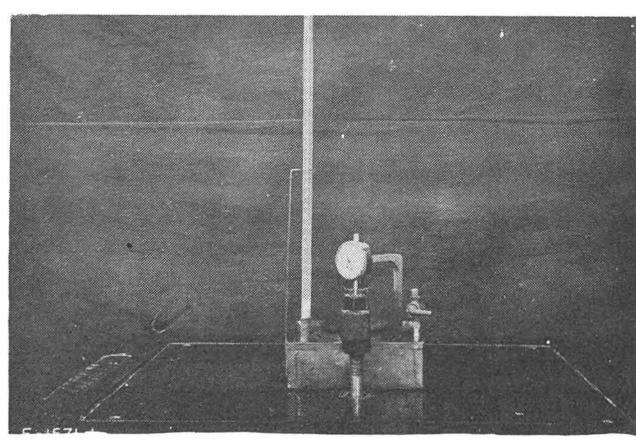
4) A calibrated standpipe for variable head measurements or a constant head device for constant head permeabilities.

5) Apparatus for de-airing the water.

6) Additional incidental equipment such as ovens, balances, graduates, etc.

b. Specimen Preparation

The samples are placed in the permeability cylinder either undisturbed or recompacted. Care must be taken to insure a good seal with the cylinder wall for the undisturbed specimens. Specimens may be sealed in rubber sleeves to prevent piping.



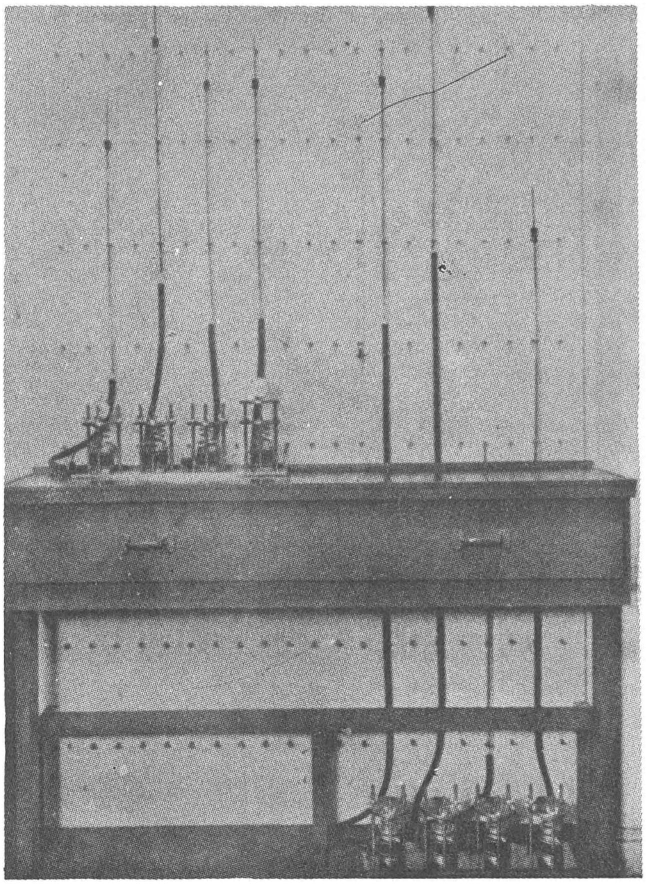
Permeability - Consolidometer with Permeability Attachment

FIG. 18

The recompacted specimen is placed at the desired conditions of moisture and density by special or standard compaction equipment.

c. Testing

1) Variable head permeability. The test is performed by measuring the quantity of water percolating through a soil in time "t"



Permeability - Constant Head Apparatus

FIG. 19

under a beginning "h_1" and a final head "h_2". The permeability is then expressed according to the following equation:

$$k = 2.3 \frac{aL}{At} \cdot \log_{10} \frac{h_1}{h_2}$$

wherein "a" is the area of the standpipe, "A" is the cross-sectional area of the specimen, "L" is the length of the specimen, "h_1" is the head at the beginning of the test, "h_2" is the head at the end of the test, and "t" is the time required for water level to drop from "h_1" to "h_2".

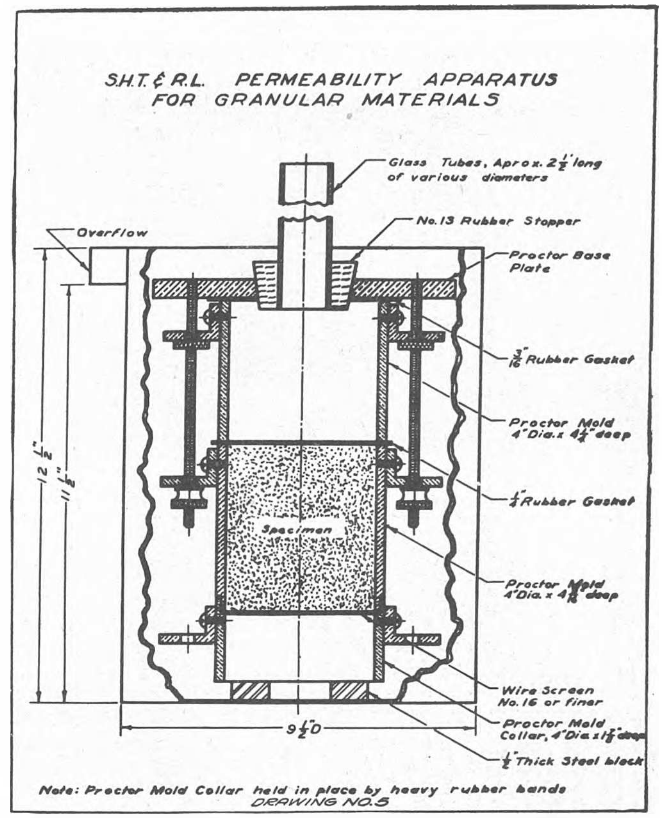
2) Constant head permeability. A Sample of soil of cross-sectional area "A", and length "L", is subjected to a flow of water under a constant head "h". From Darcy's law the coefficient of permeability can be expressed as follows:

$$k = \frac{QL}{hAt}$$

The test is performed by measuring the quantity of water, "Q", flowing through the sample, length "L", under head "h", and time "t". In either type of test, readings are usually continued until the rate reaches a constant figure. If settlement or expansion data are desired, the apparatus is set up with a calibrated spring furnishing a load to the sample as shown in Figures 15 and 16 and the deflection readings taken in conjunction with the percolation readings. Figure 21 shows some typical data sheets for the permeability tests.

The data gathered from the permeability test is useful for design purposes in selecting materials for various sections of dams, highways, dikes, airports, etc., and for estimating the seepage from irrigation canals, ditches, and reservoirs.

Detailed test procedures are given in various publications including Notes on Soil Testing for Engineering Purposes--Harvard University; Laboratory Manual of Soil Testing Procedures--University of Michigan; Laboratory Procedure in Testing Earth Materials for Foundation and Construction Purposes--Bureau of Reclamation; and Procedures for Testing Soils--American Society for Testing Materials.



Permeability - Variable Head Apparatus

FIG. 20

G. CALIFORNIA BEARING RATIO

1. General

The California Bearing Ratio Test (CBR) is an empirical procedure for measuring the relative bearing capacity of subgrades, base course materials, or materials for use in flexible pavements, by a standard penetration method. In this test, the load intensity required to proceduce penetration at a standard rate of a 3-square-inch piston into a carefully controlled sample is compared to the load intensity required to produce a like penetration under similar conditions into a standard, well-graded, crushed rock. Unit load values obtained for various depths of penetration from 0.1 to 0.5 inch into the crushed rock sample are standardized, and the values obtained for the CBR test on any sample are expressed as a percentage of this standard. In practice, the ratio at any 0.1-inch penetration is used, with the values in the first 0.1-inch assuming primary importance and ratios at any succeeding 0.1-inch penetration being used less frequently.

The CBR test is performed on recompacted or undisturbed samples under conditions as nearly identical as possible to the prototype. The amount of swell or consolidation during a

U. S. BUREAU OF RECLAMATION
EARTH LABORATORY
PERCOLATION SETTLEMENT TEST WORK SHEET

Project ____________ Feature ____________ Sample Number ____________
Cylinder Number ____________ Computed By ____________ Checked By ____________

PLACEMENT DATA

Wt. Cyl. Empty ______ #	Wt. Cyl. & Earth ______ #	Sample Depth ______ in.
Wt. 1" Layer ______ #	Wt. of Cyl. ______ #	Sample Vol. ______ c.f.
Wt. Cyl. & 1" Layer ______ #	Wt. Wet Earth ______ #	Sample Area .349 s.f.
Wt. 1" Layer ______ #	Wet Density ______ #/c.f.	Depth of Fill ______ ft.
Wt. Cyl. & 2" Layer ______ #	Plac. Mois. Cont. ______ %	Wet Wt. per ft. ______ #
Wt. 1" Layer ______ #	Plac. Dry Den.* ______ #/c.f.	Fill Load ______ #
Wt. Cyl. & 3" Layer ______ #	Desired Mois. Cont. ______ %	Jack No. ___ Read. ______

	Total	½ Total	Thickness Earth	
Dial Read. A + B w/Ring				
Dial Read. A + B No Load			÷ =	
Difference				
Consolidation Thickness			÷ =	

Date 194	Hour Obs.	Load lbs./s.f.	Travel: Dial at A Read.	Dial at A Amt.	Dial at B Read.	Dial at B Amt.	Settlement Avg. Amt.	Settlement Percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

AFTER PERCOLATION DATA

Moisture Determination ______	Consolidated Dry Density
Pan Number ______	= Placement Dry Density ÷ (100 - % Settlement)/100
Wt. Pan & Wet Soil ______	= ______ ÷ (100 —)/100 =
Wt. Pan & Dry Soil ______	
Wt. Pan ______	
Wt. of Water ______	
Wt. of Dry Soil ______	
Mois. Content ______	Penet. Resis. × =
Moist. Content ______ %	Penet. Resis. ______ p.s.i. Consol. Dry Den. ______ p.c.f.

*Also Maximum Dry Density

Remarks: ____________

Sample Number ______
Location Number ______

E.D.- 6-46

U. S. BUREAU OF RECLAMATION
EARTH MATERIALS TESTING
Sheet ___ of ___

PERCOLATION DATA SHEET

Sample No. ______ Project ______ Feature ______

Cylinder Location No. ______ Observer ______

$C = 0.0738 \frac{L'}{H_{wc}}$ $k = CF \frac{R}{t'}$

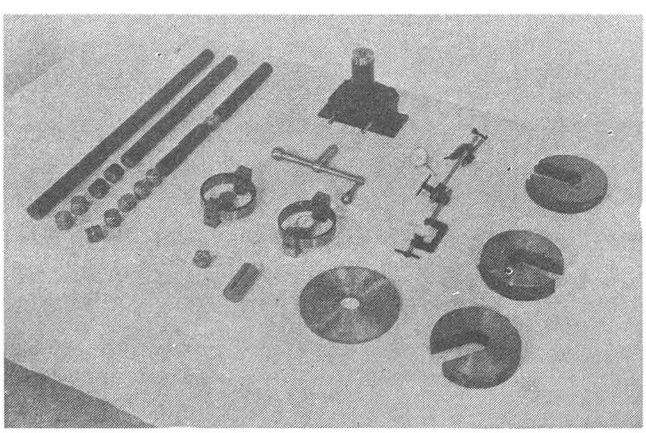
Time Installed: Date 19	Time Installed: Hour	Head Tank: No.	Head Tank: F Factor	H_{wc} head Ft.	L' Consol. Thick In.	C Constant	CF Constant

Time of Observation: 19__	Time of Observation: Hour	t' Elapsed Time Hours	Head Tank Read.	R Diff. in Read.	R/t'	k Perco. Rate Ft./yr.	Remarks

Form No. ED-35-38

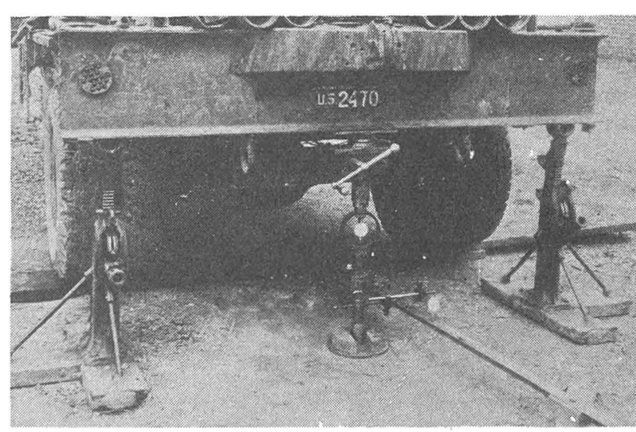
Permeability - Data Sheets

FIG. 21



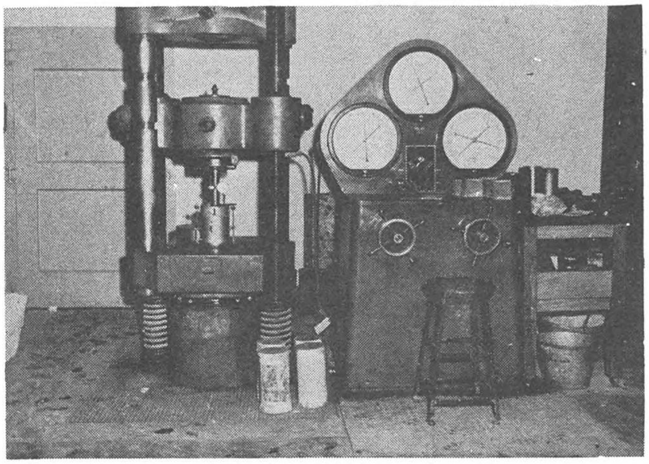
CBR Test - Field Equipment

FIG. 22



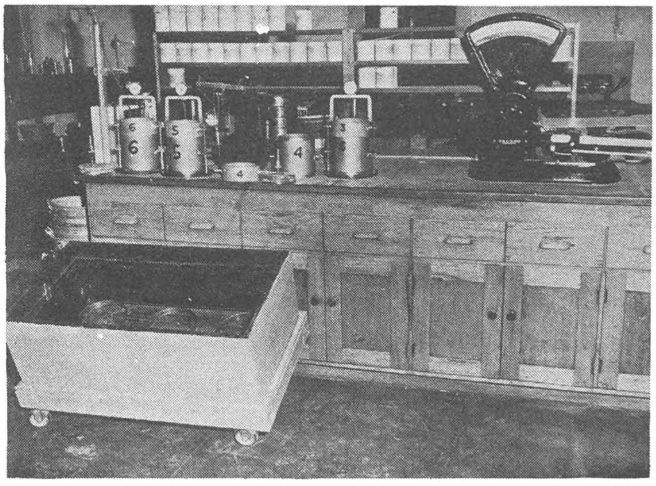
CBR Test - Field Test

FIG. 23



CBR Test - Laboratory Test

FIG. 24



CBR Test - Test Equipment

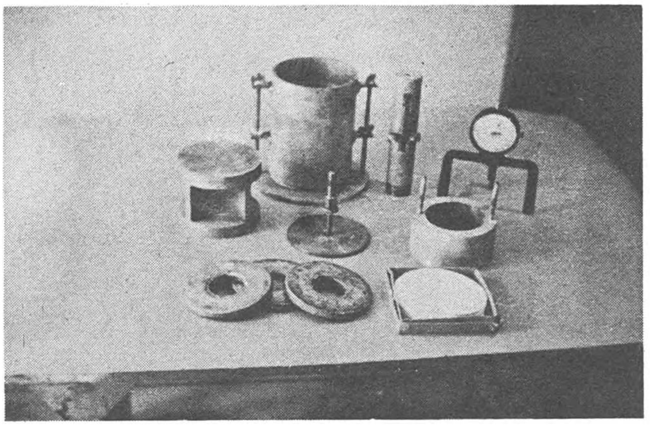
FIG. 25

saturation period is measured and the bearing ratio is obtained, both in the optimum conditions as placed in the field and in the saturated condition as might ultimately be expected in the prototype.

CBR machines and procedures are quite standard in laboratories throughout the United States with but few modifications or adaptations. The original testing procedure called for the determination of optimum moisture conditions and placement for testing by use of static loads. Many laboratories have substituted the impact method as described in Section E on compaction and penetration. During World War II the U.S. Army Aviation Engineers modified the procedures and interpretations somewhat, and used CBR for the design of flexible pavements and foundations for airdromes in areas where complete soil testing programs were not possible.

2. Testing Equipment

The U.S. Waterways Experiment Station has developed equipment and methods for a field in-place California Bearing Ratio Test. A calibrated proving ring and Walker screw jack



CBR Test - Test Equipment

FIG. 26

are utilized in subjecting the foundation or flexible pavement to the CBR test. Details of the equipment and setup for testing are shown in Figures 22 and 23, respectively.

The State Road Department of Florida uses a "soil bearing test" for testing friable A-3 materials. The soil is compacted into a 3-1/16-inch diameter by 3-1/4-inch long cylindrical brass cup by means of a static 1200-pound load. Penetration of a 1-square-inch bearing plate by loading at a rate of 1 pound every 7½ seconds is measured until a deformation of 0.01 inch in 5 seconds is obtained. The soil is considered as failing at this rate, and the penetration resistance in pounds per square inch is measured at this point.

3. California Bearing Ratio Test Procedure

a. Apparatus. The apparatus (Figures 24, 25, and 26) consist of the following:

1) CBR cylinder. A cylindrical mold 6 inches in diameter and 8 inches in height for compacting specimens.

2) Piston. A penetration piston or plunger at least 5 inches high and with an end area of 3 square inches.

3) Compaction equipment. A testing machine for static loading, or the necessary compaction equipment of the standard desired for compaction by impact.

4) Penetration equipment. A testing machine, hydraulic jack, or screw jack for producing the penetration of the piston either in the laboratory or field.

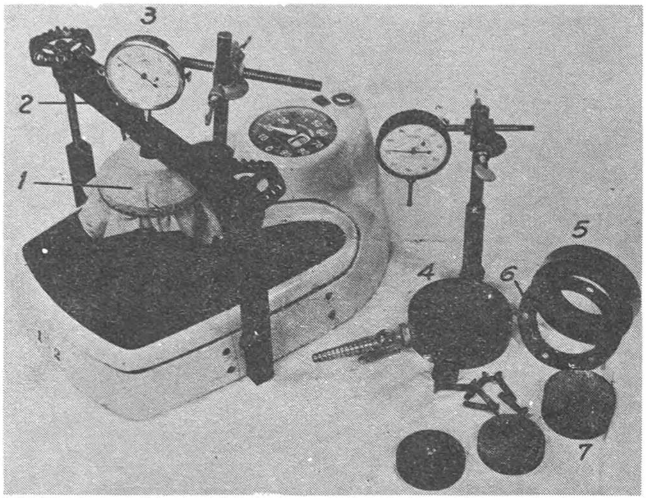
5) Perforated plate, surcharge weights, and tripod gages for measuring shrinkage or swell during the saturation period.

6) Additional incidental equipment, such as balances, dial gages, water tank, ovens, mixing bowls, cutting ring for undisturbed samples, graduates, etc.

b. Sample Preparation

1) Undisturbed samples. The soil cutting ring with CBR cylinder attached is placed upon the section where a specimen is desired. The material around the ring is trimmed down so that very little is shaved off as the cylinder and ring are forced down. Care must be exercised to prevent disturbance of the sample and provision made to prevent moisture loss. A split jacket is sometimes used to obtain an undisturbed sample.

2) Recompacted samples. The material is compacted in the CBR cylinder at optimum conditions by static load or impact methods so



Consolidation - Fixed-Ring Consolidometer

FIG. 27

as to represent the prototype in the field. The CBR test is performed on the material passing the 3/4-inch screen. In case an appreciable amount of material larger than 3/4 inch is present in the sample, the percent by weight of this portion is ascertained and a like amount of 1/4-to 3/4-inch size gravel is added to the sample.

c. Testing

1) The specimen is placed in the testing machine and the load intensity required to proceduce penetration at the rate of 0.05 inch per minute is measured (Figure 24). Readings are taken at 0.025 inch, 0.050 inch, 0.075 inch, 0.1 inch, 0.2 inch, 0.3 inch, 0.4 inch, and 0.5 inch. This specimen is then scarified and recompacted on the surface or a companion specimen prepared at identical moisture and density conditions.

2) The cylinder containing the recompacted or companion sample is immersed in water so that saturation takes place from the bottom. The shrinkage or swell is measured during a 4-day saturation period by placing a perforated plate with extension on the top of the specimen and taking periodic readings with a tripod gage.

3) After saturation, the specimen is again tested for penetration as described in (1) above.

d. Plotting

The standard values for use in determining the bearing ratio are as follows:

Penetration (inches)	Unit Load (psi)
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

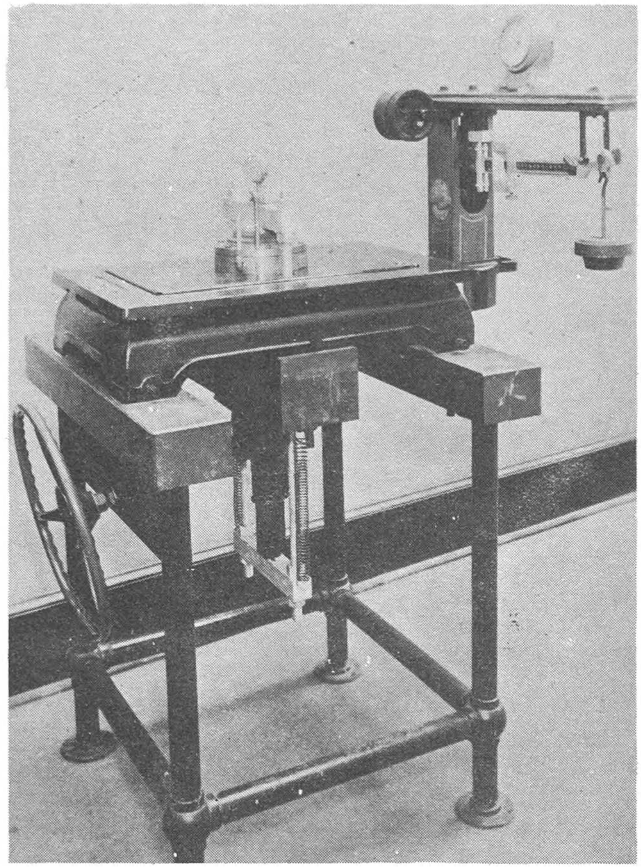
The CBR is computed as follows:

$$CBR = \frac{\text{Test Unit Load}}{\text{Standard Unit Load}} \times 100$$

The CBR used in design is the 0.1-inch value, whichever is greater. For most soils the 0.1-inch penetration is greater.

The load intensity-penetration curves for both the standard soil and the material being tested are plotted on arithmetic scales to show the character of the deformation.

Detailed test procedures may be found in articles by O.J. Porter entitled "The Preparation of Subgrades" from "Proceedings, Highway Research Board, Volume 18, Part II, and "Foundations for Flexible Pavements," Proceedings, Highway Research Board, Volume 22, Page 100. Further information may also be found in an article by T.A. Middlebrooks and Captain G.E. Bertram, entitled "Soil Tests for Design of Runway Pavements" from Proceedings, Highway Research Board, Volume 22, Page 144.



Consolidation - Fixed-Ring Consolidometer

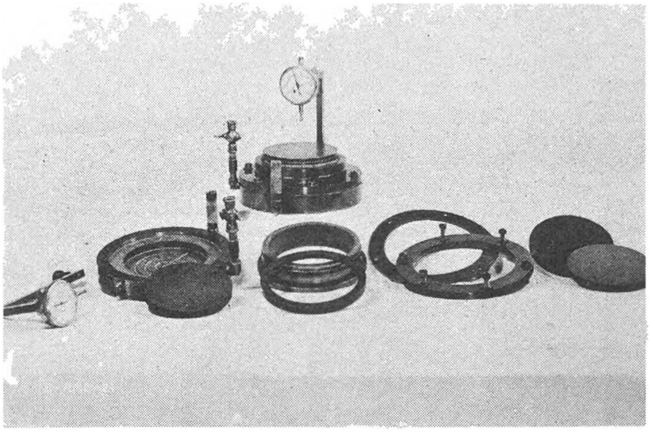
FIG. 28

H. CONSOLIDATION

1. General

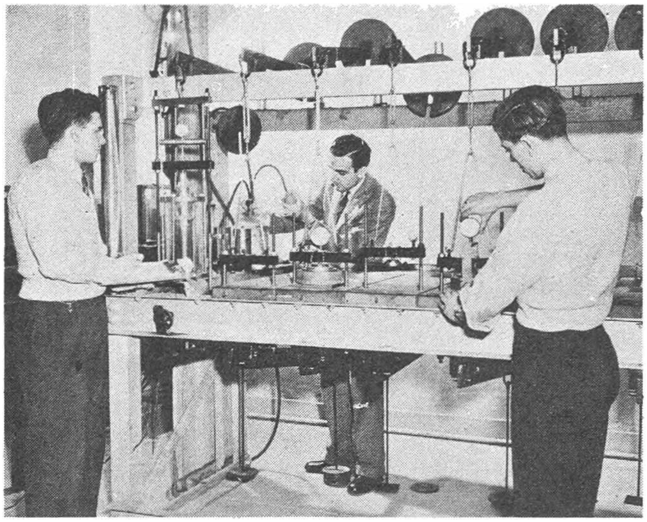
The consolidation test which is described in this section is sometimes referred to as the "one-dimensional consolidation test" and is most commonly used in the United States for determining the magnitude and rate of volume change which a laterally confined soil specimen will undergo when subjected to an axial load. In this test an incremental series of axial loads or a single axial load is applied to a cylindrical soil specimen confined by a close-fitting ring container. Porous cylindrical stones or plates are usually provided on the top and bottom of the specimen for draining or saturating the soil specimen. Permeability data are sometimes obtained during the test. Other specialized consolidation tests, such as the "three-dimensional consolidation test", are described in Section K on Miscellaneous Tests.

For the load or each increment of load, the progress of volume change, corresponding to appropriate time intervals, is measured until the volume change has ceased or has become very small. Saturation of the specimen before, dur-



Consolidation - Fixed-Ring Consolidometer

FIG. 29



Consolidation - Counter-Balanced Loading Device

FIG. 30

ing, or after consolidation is governed by the expected conditions in the structure or foundation under investigation.

Consolidation tests are made on remolded soils placed at various densities and moisture contents or on undisturbed soils cut to fit the ring container.

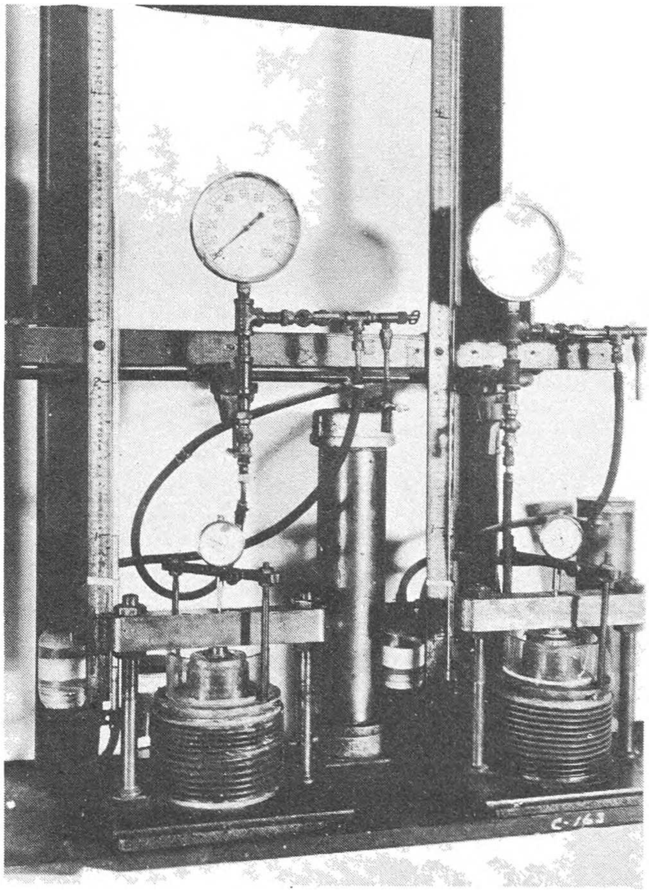
Eighty-two of the 144 laboratories interested in soil testing use the consolidation test. Consolidometers used in the various laboratories throughout the United States consist of these general types with slight variations in some cases: the cylinder with hollow piston (Terzaghi), fixed ring consolidometer with mushroom piston (Hogentogler), fixed ring (Casagrande), floating ring, and piston with floating ring. The specimen sizes generally vary from 2.0 to 5.0 inches in diameter and from 0.5 to 2.0 inches in thickness, although some equipment is available for testing soil-rock specimens up to 20 inches in diameter and 9 inches deep. The consolidating loads are applied by weights, jacks, spring, or air pressure.

2. Testing Equipment

Consolidometers of both the Terzaghi and the Casagrande types are used at the California Institute of Technology. Loads are applied by two methods: 1) weights on beams supported by knife edges and 2) a yoke which screws down and presses the soil sampling equipment against a scale. Figure 27 shows this latter simple and unique loading equipment. Both of these instruments are so designed that a one-ring specimen taken from the sampling equipment fits directly into the machine without removing the soil from the ring. The sample is 2.41 inches in diameter and 1 inch thick. Thicknesses less than 1 inch can be used if desired.

The Massachusetts Institute of Technology soil laboratory has five units of the Casagrande type consolidometers with platform scale and yoke loading devices. The devices are equipped with consolidometers of 4-1/4-inch diameter (8 tons per square foot capacity) and 2-3/4-inch diameter adapters (16 tons per square foot capacity). One unit has a higher capacity scale and a special leverage system permitting approximately six times as large capacities as given above. Larger special consolidometers are provided for research, as well as devices for measuring pore water pressures at base of samples during consolidation. Figure 28 shows an entire M.I.T. consolidation unit.

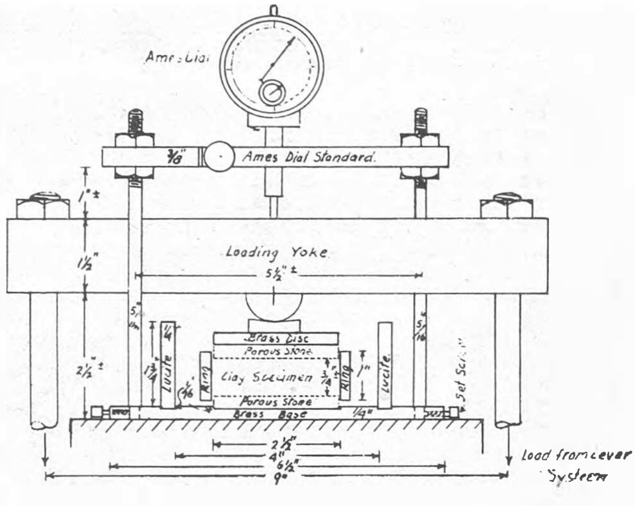
Similar fixed-ring consolidometers and



Consolidation - Pneumatic Loading Device

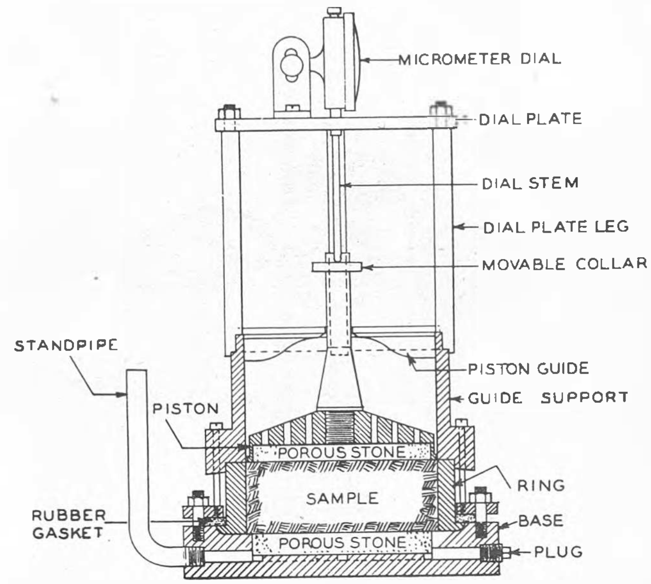
FIG. 31

scale loading units are used by the Ohio State Highway Laboratory, The Texas A&M College, Harvard University, the U.S. Bureau of Reclamation, and the U.S. Engineers, Waterways Experiment Station Laboratory. Figure 29 is a picture of an unassembled fixed-ring consolidometer used at the Bureau of Reclamation.



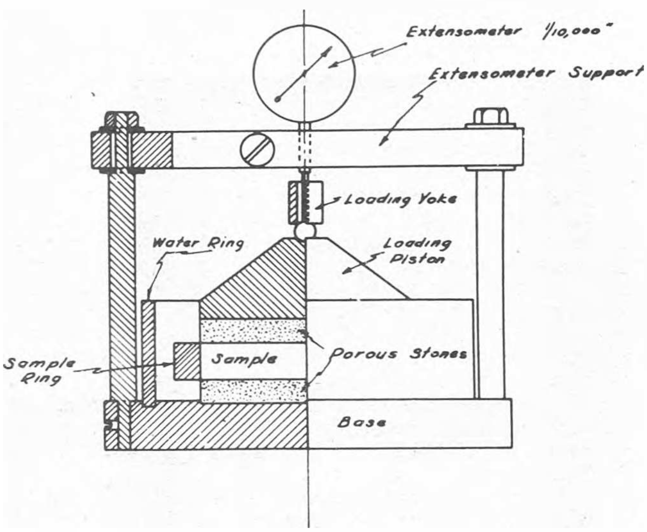
Consolidation - Floating-Ring Consolidometer

FIG. 32



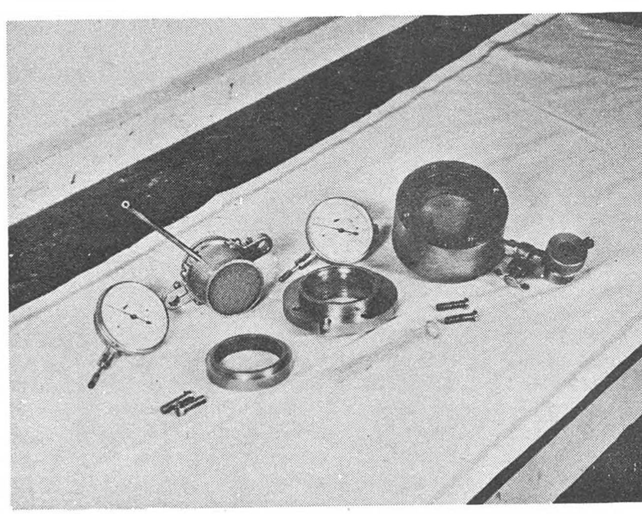
Consolidation - Mushroom Piston Consolidometer

FIG. 34



Consolidation - Improved Floating-Ring Consolidometer

FIG. 33



Consolidation - Unassembled Hollow Piston Consolidometer

FIG. 35

Many laboratories are now using large loading frames capable of accommodating a number of consolidation or triaxial shear units, or any other test units requiring the application of vertical loads. A typical bank of counter-balanced loading devices as used by the New York University is shown by Figure 30. Other institutions using such a loading frame are the Harvard and Purdue Universities. Other types of counterbalanced consolidometer loading devices are used by the Rensselaer Polytechnic Institute and the Navy Department, Bureau of Yards and Docks.

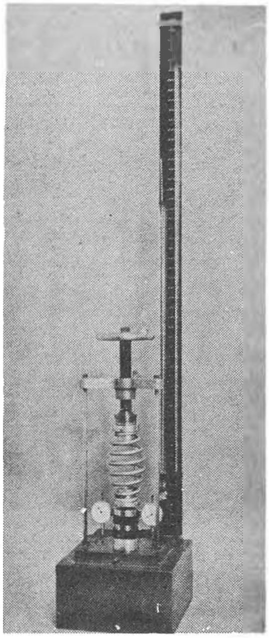
Columbia University has four loading machines of the counter-balanced lever system type with calibrated dead weights and six loading machines (see Figure 31) using 6-inch diameter Fulton-Sylphon bellows of 75-pound per square inch capacity with the pressure held constant by sensitive air reducing valves. The air pressure is measured by a mercury manometer for pressures on the soil specimen of 1 to 4 kilograms per square centimeter, depending upon the size of the consolidation ring, and by calibrated pressure gages for higher pressures up to 16 kilograms per square centimeter. Figure 32 is a sketch of the floating-ring consolidometer used at this laboratory.

Improvements in the floating-ring consolidometer as used at the University of Texas are shown in the sketch Figure 33. These include a removable water ring, facilitating the placing of the sample, and a movable extensometer support for centering the extensometer.

Figure 34 is a sketch of the mushroom piston consolidometer used at the University of Maryland.

An unassembled hollow-piston consolidometer is shown in Figure 35. Specimens 1.938 inches in diameter and 0.5 inch thick are consolidated in loading increments of 0.25 to 16.0 tons per square foot. This consolidometer is used by the Bureau of Yards and Docks.

The firm of Dames and Moore uses the cylinder consolidometer, loaded by a calibrated



Consolidation - Spring Loading Device

FIG.36

spring as shown in Figure 36.

The "Proctor" percolation-settlement apparatus is used by a number of laboratories to determine settlement characteristics of remolded soils during the permeability test. This apparatus usually is used for soil specimens about 8 inches in diameter and 3 inches thick. The equipment is primarily a fixed ring consolidometer with a mushroom piston and usually is equipped with a selfcontained spring loading unit. The Bureau of Reclamation also has six large units of a similar percolation-settlement device which accommodates remolded soil-rock specimens 20 inches in diameter and 9 inches thick. Figures 15 and 16 show these apparatus.

3. Test Procedure

a. Apparatus. The apparatus usually consists of the following:

1) Soil cutter. A cylindrical ring, sharpened on the outside, of the same diameter as the consolidometer ring, and a device for producing a controlled axial movement of the cutting ring.

2) Trimmers. Instruments such as a piano wire saw, knives, spatulas, etc.

3) Consolidometer. A cylindrical ring to hold the soil sample with a porous stone above and below and appurtenances permitting immersion or saturation of the specimen.

4) Loading device. A device for applying constant static loads to the consolidometer.

5) Additional incidental equipment such as, ovens,balances, evaporating dishes, etc.

b. Sample preparation

1) Preparation of remolded or compacted specimen. Sufficient soil to fill the ring container is compacted or compressed into the container to the required height, usually at optimum moisture and to maximum density. An extension collar for the container may be provided, as at the Bureau of Reclamation, in which case excess soil is compacted and then trimmed to the required height after removal of the collar.

2) Preparation of undisturbed specimen. The soil cutting bit with consolidometer ring attached is set on top of the undisturbed soil sample from which the specimen is to be cut. Material is trimmed with a knife close to the cutting edge of the bit, leaving a very little material for the bit to shave off as it is gently pressed downward. When the sample protrudes above the container ring, it is trimmed off with a straight edge. The cutting bit is removed and the sample trimmed to the level of the ring container. During the cutting and trimming operations, great care should be taken to minimize disturbance of the sample and loss of moisture. This is the cutting procedure followed at the Bureau of Reclamation. The University of Maryland and the Public Roads Administration use a cutter the same height as the consolidometer ring. The specimen is extruded to the consolidometer ring after cutting and trimming. The net weight of soil specimen can be determined by weighing the specimen and ring container, and the moisture content can be determined by drying a portion of the trimmings or the entire specimen.

c. Testing

1) Extensometer readings are made with a steel blank of desired sample thickness in place of the soil specimen to establish a dial reading for a known thickness of sample. The initial sample thickness is determined by placing the assembled consolidometer (with specimen) in the loading divice and applying a light load to the specimen after which a dial reading is taken and compared to the reading taken with the steel blank.

2) One axial load or incremental loads are applied to the specimen. The initial load is maintained until the consolidation has ceased or become very small. Extensometer readings are taken at appropriate time intervals for determining the magnitude and rate of consolidation. This same procedure is followed for each succeeding load increment.

3) Saturation and permeability facilities are provided on most consolidometers. Whether saturation of the specimen is provided before, during, or after loading depends on the anticipated field condition being investigated. Foundation samples below watertable would probably be saturated before loading. Dam foundation materials above watertable and the dam material itself would probably be saturated after loading; this simulates field conditions in which saturation of the foundation and dam will occur after the reservoir is filled. Permeability rates of the specimen can be determined during or after saturation if desired. See Section F for information on permeability.

4) After consolidation under the maximum applied load and saturation and permeability information is complete, the load is removed. Expansion or rebound information may be taken at this time by allowing the extensometer to remain in the loading apparatus and reading the extensometer until movement has cased.

5) Using the data gathered from the consolidation test, such as, amount of soil used, dial readings, loads applied, moisture content, etc. the time-consolidation, load-consolidation, densities, and void ratio variations can be utilized for design purposes. Figure 37 shows a typical set of

VIII-a

Name ______________ Sample & Test No. __________

Date ______________ Sheet No. __________

CONSOLIDATION TEST

WATER CONTENT DETERMINATIONS
COMPUTATION SHEET

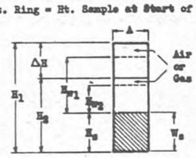
SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Description of Sample: ______________________________

W. C. Determination	At Start of Test		At End of Test	
Ring and Glass Plate Nos.				
Wt. Sample Wet + Tare				
Wt. Sample Dry + Tare				
Wt. of Water				
Tare				
Wt. of Dry Soil, W_s				
Water Content w%	w_1 =	w_1 =	w_2 =	w_2 =
Average w%	w_1 =		w_2 =	

Number of Test Ring: __________ Area of Test Ring A = __________ cm.^{2}

Ht. Ring = Ht. Sample at Start of Test = H_1 = __________ cm.



Specific Gravity of Solids = s_s = __________ Det. ☐ Est. ☐

Reduced Ht. (Solid Matter) = $H_s = \frac{W_s}{A \cdot s_s}$

H_s = __________ = __________ cm.

Change in Ht. of Sample from Beginning to End of Test = ΔH = __________ cm.

Ht. of Sample at End: $H_2 = H_1 - \Delta H$ = __________ = __________ cm.

Ht. of Water at Start: $H_{w1} = w_1 \cdot H_s \cdot s_s$ = __________ = __________ cm.

Ht. of Water at End: $H_{w2} = w_2 \cdot H_s \cdot s_s$ = __________ = __________ cm.

Degree of Saturation at Start of Test: $G_1 = \frac{H_{w1}}{H_1 - H_s}$ = __________ = __________

Degree of Saturation at End of Test: $G_2 = \frac{H_{w2}}{H_2 - H_s}$ = __________ = __________

FOR COMPUTATION OF VOID RATIO USE THE FOLLOWING VALUES:

H_s = __________ cm. H_1 = __________ cm.

REMARKS: ______________________________

VIII-b

Name ______________ Sample & Test No. __________

Date ______________ Sheet No. __________

CONSOLIDATION TEST

DATA SHEET

SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Notes: Temp. refers to sample temperature.
Note on separate line each time dial is reset.

Date	Time	Temp °C	Load kg	Elapsed Time	Dial Reading	Date	Time	Temp °C	Load kg	Elapsed Time	Dial Reading

VIII-c

Name ______________ Sample & Test No. __________

Date ______________ Sheet No. __________

CONSOLIDATION TEST

SUMMARY & COMPUTATION SHEET

SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Duration of Test: ______________

Time Interval Between Load Increments for Computation: ______________

For Computations (from Sheet No. ____): H_s = _____ cm. H_1 = _____ cm.

Void Ratio Computation: (For relatively incompressible soils compute void ratio to four significant figures.)

Date Increment was Applied	Actual Elapsed Time for Increment	Load kg. P	Pressure kg.cm.$^{-2}$ p	Dial Reading cm. R_D'	Correction	Corrected Dial Reading R_D	$\frac{R_D}{H_s}$	Void Ratio e	Water Content $w = \frac{e}{s}$	Remarks

VIII-d

Name ______________ Sample & Test No. __________

Date ______________ Sheet No. __________

CONSTANT HEAD PERMEABILITY TEST

WITH CONSOLIDATION PERMEAMETER

SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Area of Test Ring = A = __________ cm.^{2}

Height of Sample at Start of Consolidation Test = H_1 = __________ cm.

Height of Sample for Permeability Test = H = H_1 - Total Compression in cm.

$H = H_1$ - Dial Reading (cm.) = __________ = __________ cm.

h_a = air pressure expressed in cm. of water.

Coefficient of Permeability at Test Temperature = k_T [cm. sec.$^{-1}$]

$$k_T = \frac{Q}{i \cdot A \cdot t_{sec.}} = \frac{Q}{i \cdot A \cdot t_{min.}} \cdot \frac{1}{60}$$

$$i = \frac{\text{Average head in cm.}}{\text{Ht. of Sample in cm.}} = \frac{h_1 + h_2 + 2h_a}{2H}$$

$$k_T = \frac{H}{30 \cdot A} \cdot \frac{Q}{t} \cdot \frac{1}{h_1 + h_2 + 2h_a} = \_\_\_\_\_\_ \frac{Q}{t} \cdot \frac{1}{h_1 + h_2 + 2h_a}$$

$$k_{20} = k_T \frac{\nu_T}{\nu_{20}}$$

Temp. of Sample	Load kg.	Dial Reading cm.	Elapsed Time t min.	Head at Start h_1 cm.	Head at End h_2 cm.	$h_1+h_2+2h_a$	Quantity Q cm.^{3}	$\frac{Q}{t}$	k_T $\frac{cm.}{sec.}$	k_{20} $\frac{cm.}{sec.}$

REMARKS:

PRECAUTIONS: (1) The maximum head used must not be greater than thirty per cent of the total downward pressure on the sample.

(2) Increase in volume of the sample during test must be observed on the extensometer and the flow of water continued until no further expansion takes place. After this condition is reached, standpipe readings may be used for the computation of the coefficient of permeability.

Consolidation - Data Sheets

FIG. 37

consolidation data sheets as used at the Harvard University Laboratory.

d. Plotting

At the Bureau of Reclamation, the stress-strain relationship is shown by plotting both pressure and percentage reduction in thickness or the voids-ratio change on arithmetic scales. The University of Maryland and the Public Roads Administration show the stress-strain relationship by plotting the pressures as abscissas to a logarithmic scale and the percentage reduction in thickness as ordinates to an arithmetic scale.

The time-consolidation relationship is shown at the Bureau of Reclamation by plotting the time as abscissas to a logarithmic scale and the consolidation as ordinates to an arithmetic scale. At the University of Maryland and the Public Roads Administration, this relationship is shown by plotting the square root of time as abscissas and the percentage consolidation as ordinates. Figure 37 shows a set of typical consolidation data sheets.

Detailed test procedures are given in various publications including: Notes on Soil Testing for Engineering Purposes--Harvard University; Laboratory Manual of Soil Testing Procedures--University of Michigan; Laboratory Procedure in Testing Earth Materials for Foundation and Construction Purposes--Bureau of Reclamation; Research on Consolidation of Clays by D.W. Taylor--Massachusetts Institute of Technology; and Procedures for Testing Soils--American Society for Testing Materials.

I. DIRECT SHEAR

1. General

The direct shear test which is described in this section is commonly used in the United States for determining the resistance of soils to lateral distortion. The triaxial shear test which is also used for determining the shearing resistance of soils is described in Section J. In the direct shear test, a shearing force is applied to a specimen under a normal load. The normal load is usually maintained constant throughout the test, and the shearing load may be applied in increments at a constant rate or at a rate which will produce a uniform rate of deformation of the specimen.

Direct shear tests are made on remolded soils placed at desired densities and moisture contents or on undisturbed soils which are cut to fit the shear box.

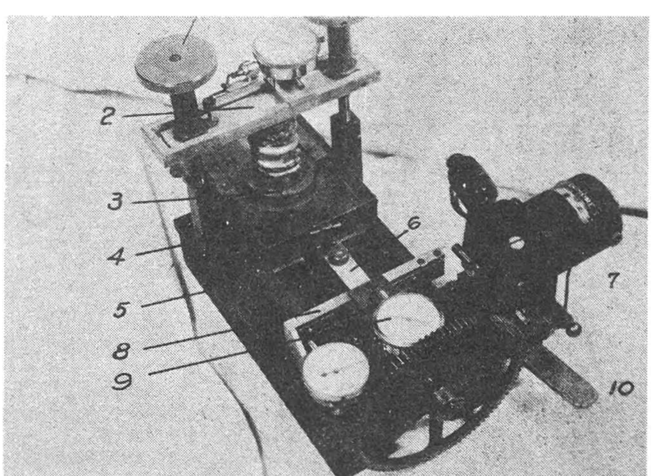
Direct shear machines used in the various laboratories throughout the United States may be divided into two main groups: (1) box and (2) double shear. The specimen sizes vary, in general, from 1.13 to 4.5 inches in diameter for circular specimens and from 2 by 2 inches to 12 by 20 inches for rectangular specimens and from 0.34 to 4 inches in thickness. The normal loads are applied by compressed gas, screws, or weights and levers. The shearing loads are applied by the same means as the normal load and, in addition, by pulley and weights, hydraulic jack, and bell crank and weights.

Sixty-four of the 144 laboratories having soils testing facilities use the direct shear test.

2. Testing Equipment

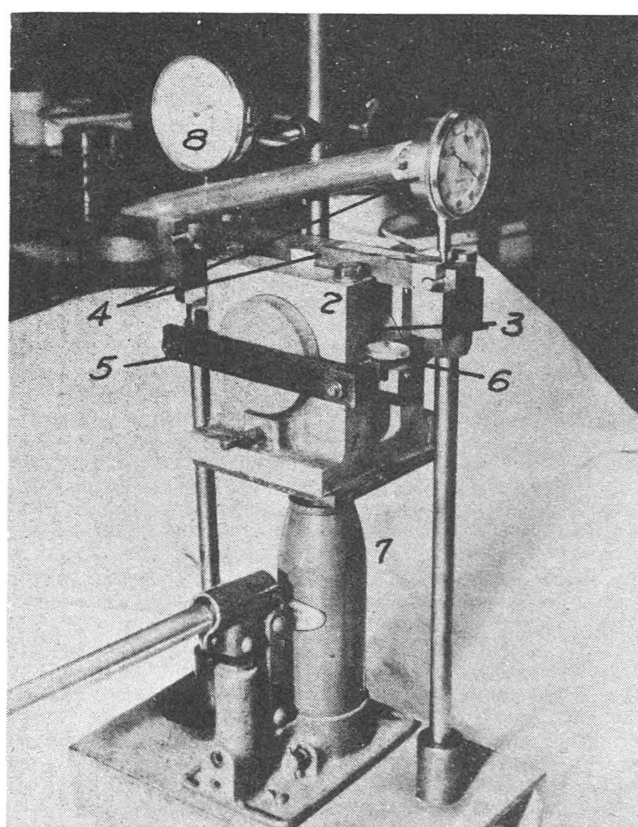
The California Institute of Technology soil laboratory uses both the box (two-ring) and the double shear (three-ring) types of direct shear machines. The normal load on the two-ring machine is applied by either of two methods: (1) by screws through a compression spring, or (2) by weights through a beam supported on knife edges. The shearing force is applied by a motor driven screw. Figure 38 shows this machine which accommodates a soil specimen $2\frac{1}{2}$ inches in diameter and up to 2 inches thick.

The three-ring shearing machine is designed to test a specimen $2\frac{1}{2}$ inches in diameter by 3 inches long, 1 inch in each ring. The nor-



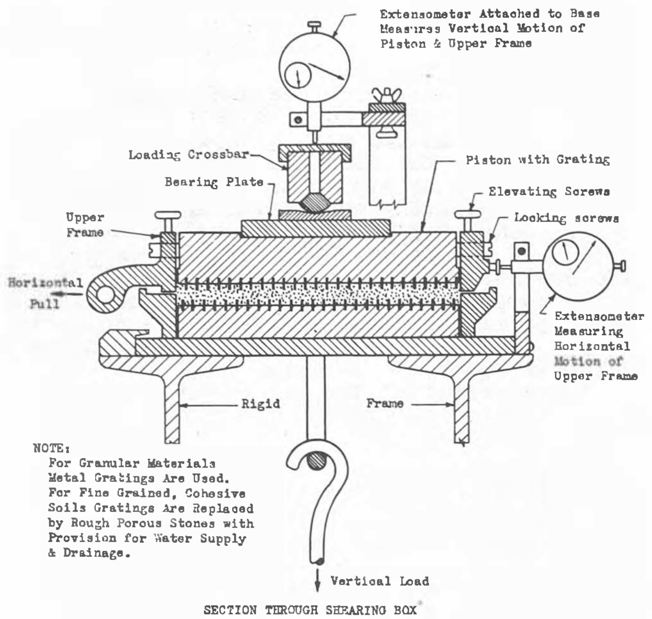
Direct Shear - Two-Ring Apparatus

FIG. 38

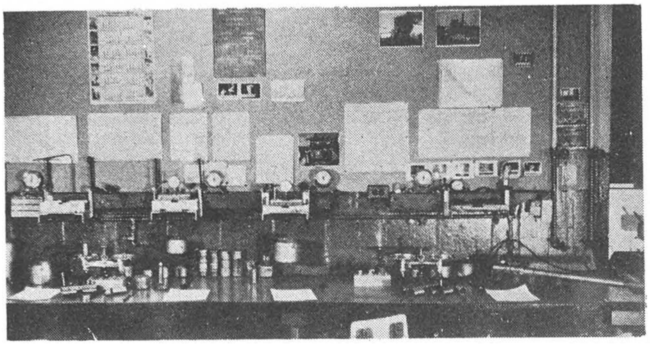


Direct Shear - Three-Ring Apparatus

FIG. 39



Direct Shear - Box Type Apparatus
FIG. 40



Direct Shear - Double Shear Apparatus
FIG. 41

mal load is applied by screws through a compression spring. The shearing load is applied by a hydraulic jack which raises the shearing frame and presses the center loading block against a fixed beam gage. This machine is shown in Figure 39.

The box type shear machine is used by Columbia University, Ohio State Highway, Bureau of Yards and Docks, University of Utah, New York Board of Water Supply, Notre Dame University, Massachusetts Institute of Technology, Harvard University, and the University of Maryland. The Bureau of Reclamation had two direct shear machines of this type, but has abandoned them in favor of the triaxial shear method. The machine used by Harvard University is shown by the section view, Figure 40.

A battery of double shear machines as used by the University of Michigan is shown in Figure 41. This type is also used by Dames and Moore laboratory.

3. Test Procedure

a. Apparatus. The apparatus usually consists of the following:

1) Specimen cutter. A cutter for forming specimens to fit the shear box. Some laboratories have sampling equipment into which the shear rings fit so that the sample is taken directly into the shear rings in the field, thus eliminating the trimming operation in the laboratory.

2) Trimmers. Knives, straight-edge trimmer, spatulas, piano wire saw, etc.

3) Shear device. Frames or boxes which contain the specimen and means of applying normal and shearing loads with provisions for measuring deformations. Pervious or impervious gratings or stones may be provided at the ends of the specimens. See Paragraph 2 for methods of loading.

4) Miscellaneous equipment, such as, ovens, balances, mixing pans, evaporating dishes, etc.

b. Specimen Preparation

1) Undisturbed samples. The cutter is placed on the sample and the material is trimmed with a knife close to the cutting edge of the bit so that only a very small amount of material is removed by the cutter as it goes down over the specimen. Great care should be exercised in the specimen preparation in order to minimize disturbance and moisture loss. If the samples are taken in the shear rings in the field, then it is only necessary to smooth the ends and the specimen is ready for testing. The wet weight and moisture content of the specimen may be determined prior to the shear test.

2) Remolded samples. A sufficient amount of material at the desired moisture content is placed in the shear boxes or rings and compacted to the desired density.

c. Testing

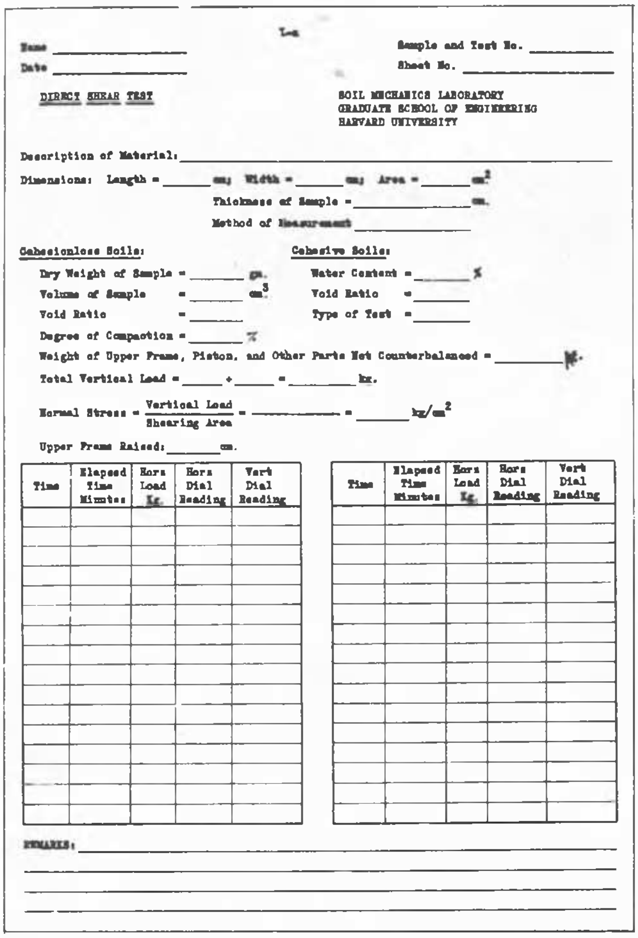
1) The shear boxes or rings containing the soil specimen are placed on the loading device and extensometer readings made for zero deformation. The boxes or rings must have clearance so they do not touch each other during the test. In the "quick test", the specimen is sheared rapidly after the application of the normal load. The "consolidated quick test" is similar to the preceding test, except that the material is allowed to consolidate fully under the normal load before the shearing force is applied. In the "slow test" the specimen is allowed to consolidate fully under the normal load and then the shearing load is applied slowly so that practically no hydrostatic pressures are built up in the pore water during the test. Porous gratings are used on the ends of the specimen in this test procedure.

2) During the test, both consolidating and shearing deformations are usually read on strain dials. The normal loads may be determined from weights or a gage and the shearing loads are generally determined by weights or a proving ring. Data sheets for recording direct shear information, as used at Harvard University, are shown as Figure 42.

3) From the data obtained from several specimens of the same material, tested under different normal load, a relationship between the shearing stress and normal load may be obtained.

d. Plotting

One common method of plotting the shear test data, as used by the University of Michigan, is to plot the values of ultimate shear stress against their respective normal loads and draw a curve through the points. Generally, the curve will become tangent to a straight line for the higher normal loads, while the slopes will be



I-a

Name ______________ Sample and Test No. __________

Date ______________ Sheet No. __________

DIRECT SHEAR TEST

SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Description of Material: ______________

Dimensions: Length = ______ cm; Width = ______ cm; Area = ______ cm^2

Thickness of Sample = ______ cm.

Method of Measurement ______

Cohesionless Soils:

Dry Weight of Sample = ______ gm.

Volume of Sample = ______ cm^3

Void Ratio = ______

Degree of Compaction = ______ %

Cohesive Soils:

Water Content = ______ %

Void Ratio = ______

Type of Test = ______

Weight of Upper Frame, Piston, and Other Parts Not Counterbalanced = ______ kg.

Total Vertical Load = ______ + ______ = ______ kg.

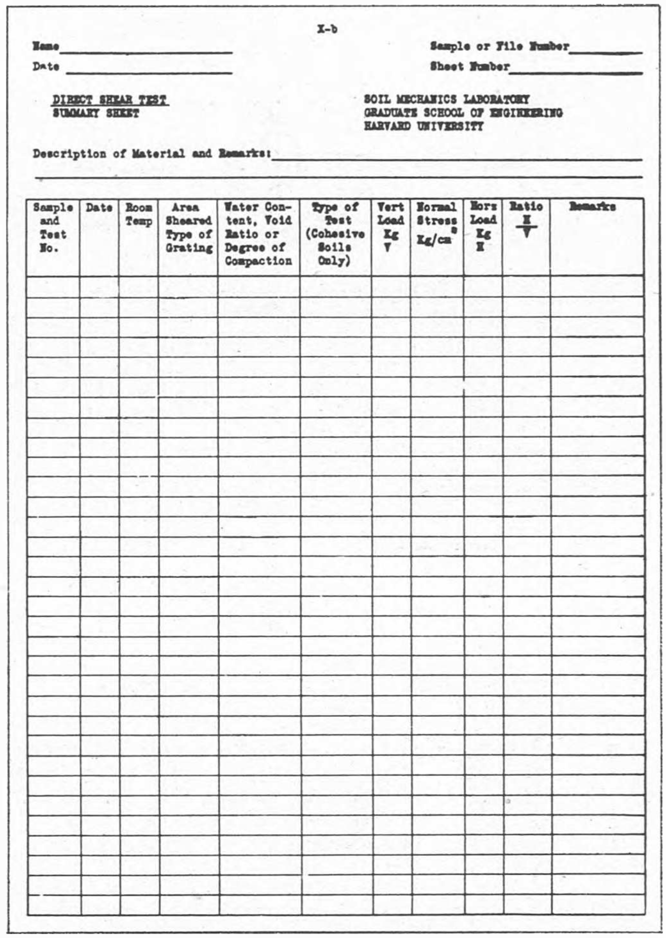
Normal Stress = $\frac{\text{Vertical Load}}{\text{Shearing Area}}$ = ______ = ______ kg/cm^2

Upper Frame Raised: ______ cm.

Time	Elapsed Time Minutes	Horz Load Kg.	Horz Dial Reading	Vert Dial Reading

Time	Elapsed Time Minutes	Horz Load Kg.	Horz Dial Reading	Vert Dial Reading

REMARKS: ______________



X-b

Name ______________ Sample or File Number __________

Date ______________ Sheet Number __________

DIRECT SHEAR TEST
SUMMARY SHEET

SOIL MECHANICS LABORATORY
GRADUATE SCHOOL OF ENGINEERING
HARVARD UNIVERSITY

Description of Material and Remarks: ______________

Sample and Test No.	Date	Room Temp	Area Sheared Type of Grating	Water Content, Void Ratio or Degree of Compaction	Type of Test (Cohesive Soils Only)	Vert Load Kg V	Normal Stress Kg/cm^2	Horz Load Kg H	Ratio $\frac{H}{V}$	Remarks

Direct Shear - Data Sheets

FIG. 42

steeper near the origin of the curve. The slope of the curve represents the tangent of the apparent angle of internal friction, Ø, and will generally be a maximum value at the origin and a minimum at the higher normal pressures. The intercept of the curve with the y axis represents the apparent cohesion of the soil and is the shearing stress with zero normal load.

Detailed procedures for conducting the test are given in several publications, including: Procedures for Testing Soils--American Society for Testing Materials, Note on Soil Testing for Engineering Purposes--Harvard University, and Laboratory Manual of Soil Testing Procedures--University of Michigan.

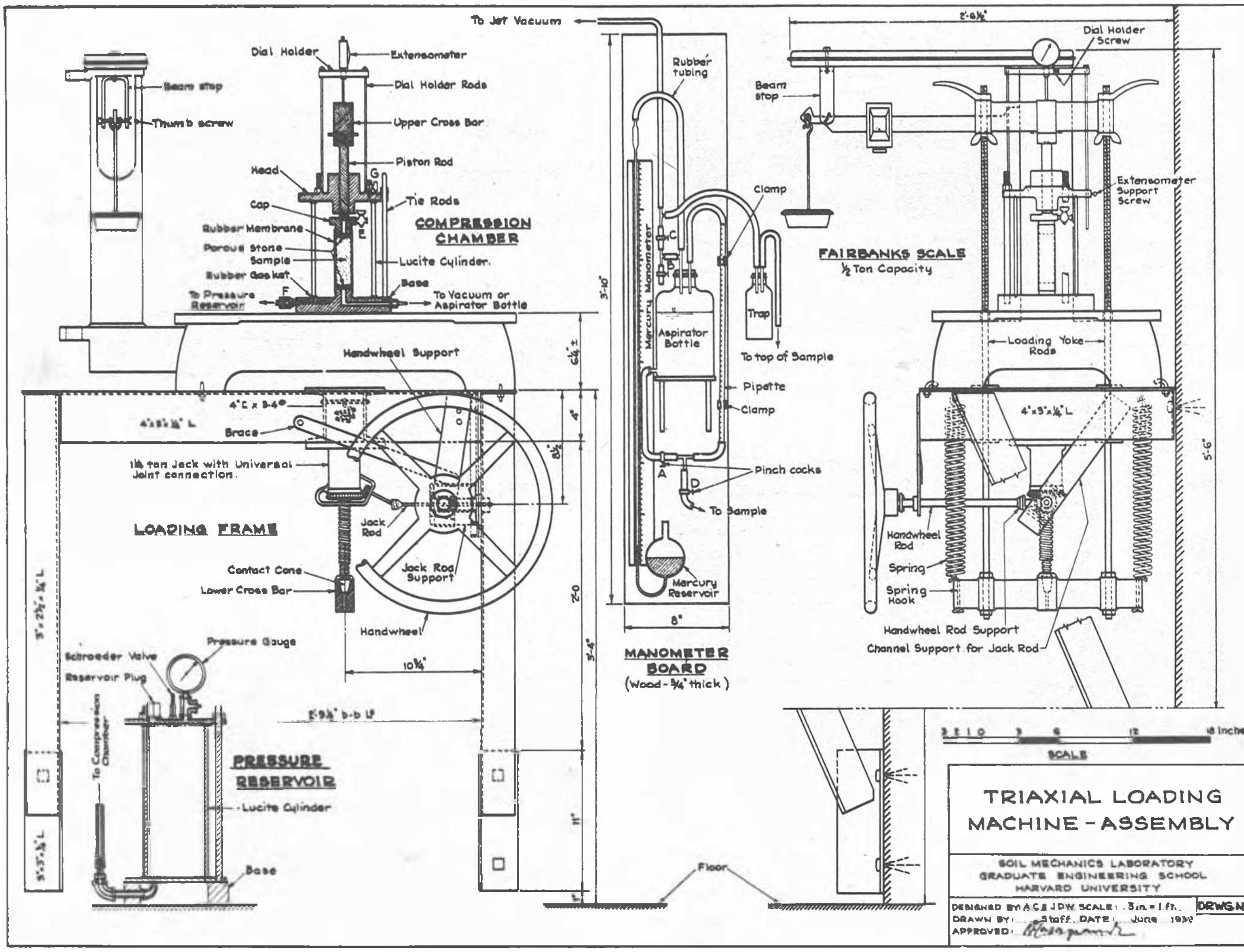
J. TRIAXIAL COMPRESSION

1. General

The triaxial compression test, which is also referred to as triaxial shear or stabilometer tests, is performed to determine the stress-deformation and strength characteristics of soils which are subjected to shearing stresses. The angle of internal friction and cohesion of the soil may be determined from an analysis of the test data. The idea of axial compression with lateral support is the fundamental principal of the triaxial compression test. In the usual type of apparatus, two of the principal stresses are produced equally by fluid pressure surrounding a cylindrical specimen, the third principal stress being applied as an axial load at the ends of the specimen. The fluid pressures are commonly referred to as the applied lateral pressures and the axial loads as the applied axial pressures. The unconfined compression test, which is used by many institutions, is considered herein as a special application of the triaxial compression test where the applied lateral pressure is zero (atmospheric). This latter test has been found to be particularly advantageous for studying saturated homogenous clay soils.

The test equipment, test procedures, and interpretation of data vary considerably throughout the United States. As the testing equipment and procedures have been developed through individual research according to individual problems, very little standardization has taken place. In view of the complexity and variety of individual problems, and the large amount of research work required in this field of soil mechanics, it is probable that a standardization of the test will not be obtained for several years. Such a standardized test would have to be extremely flexible to allow the determination of data for a variety of conditions and problems.

Most investigators prefer to use two testing techniques, one for cohesionless soils and one for cohesive soils. Two values of test data may be obtained during the shear test. For instance, the angle of internal friction obtained by a completely drained sand specimen is assumed to represent the "true" friction value, while



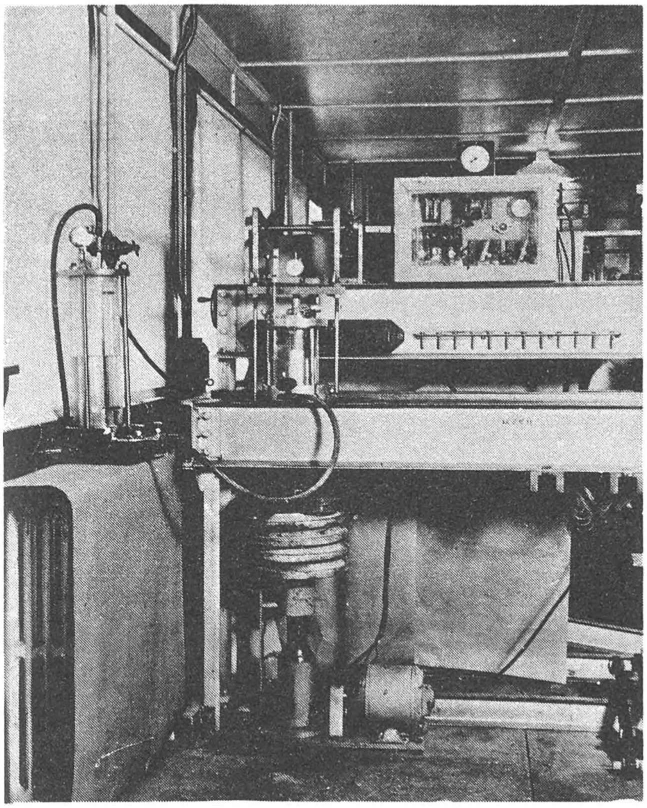
Triaxial Shear - Platform Loading Device

FIG.43

the uncorrected values obtained from tests on sealed (undrained) specimens of sand or clay (containing various degrees of moisture)--or partially drained specimens--provide an "apparent" internal friction value. Many investigators use these values as such. Some investigators, on the other hand, perform all triaxial compression tests in a sealed condition, unless complete drainage can be readily obtained, and observe the pressure built up in the pore fluid (gas and water) during the application of load. These applied pressures are then reduced by the amount of the measured pore pressures to obtain the effective particle contact pressures. It is assumed that this correction for pore pressure allows the determination of the "true" shear values. In all cases, the consolidation, drainage, or saturation of shear specimens, prior to loading in the triaxial compression test, is dependent upon the existing conditions or expected conditions in the structure or foundation under investigation.

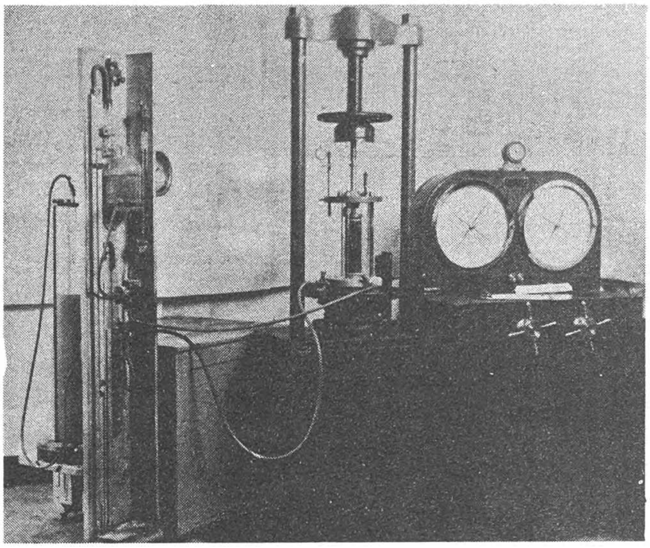
The present practice of some investigators of cohesive soils is to conduct a "quick" test to determine the shear values when no consolidation is allowed. When consolidation (or swelling) is to be considered, the "consolidated quick" or "slow" tests may be performed. From the shear test data, including the rate of load application, as well as separate consolidation data, the available shear strength is determined. While some investigators determine the shear values of "Ø" (internal friction angle) and "c" (cohesion), others prefer to use the total shear resistance values for various applied stress conditions.

Some investigators classify the soil masses to be tested as "cohesionless soils", "saturated homogeneous clays", and "partially saturated cohesive soils", the test procedures used depending upon the classification group into which the materials fall. For instance, the "cohesionless" soils are tested at several void ratios bracketing the probable range of field values. The "saturated homogeneous clays" are tested by "unconfined", "quick", and "consolidated quick" triaxial shear tests. No definite procedure is recommended for the "partially saturated cohesive soils", in this case, the procedure used depending upon the existing field conditions. Visual classification may be aided by Atterberg tests, and unconfined compression tests on undisturbed and remolded specimens at natural and other water contents. These compression tests are valuable in studying the similarity of strength characteristics of different specimens, the effect of water content on strength, and the degree of natural structure or disturbance to specimens. The details of these tests and the use of the data



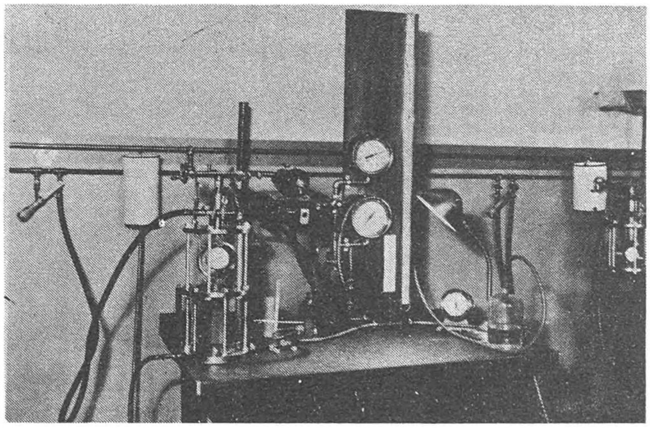
Triaxial Shear - Repetitive Loading Device

FIG. 44



Triaxial Shear - Universal Loading Device

FIG. 45



Triaxial Shear - Motor Controlled Loading Device

FIG. 46

are more fully discussed in the progress report, Triaxial Shear Research and Pore Pressure Distribution Studies on Soils, Corps of Engineers, War Department.

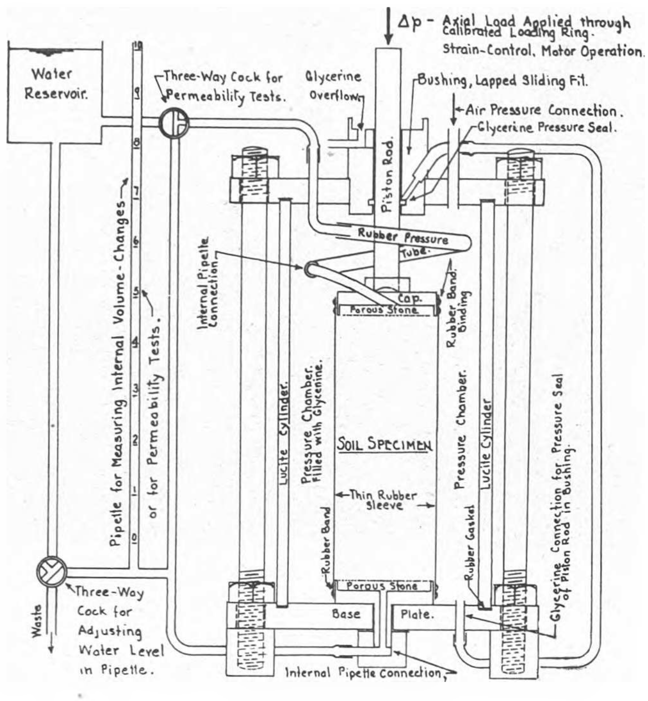
2. Testing Equipment

Sixty-four of the 144 laboratories interested in soil testing indicated that they were equipped with triaxial compression testing devices. The equipment, like the testing techniques, vary considerably throughout the country. In general, the equipment provides for tests on cylindrical specimens enclosed in airtight rubber membranes. These membranes are fastened to solid or porous end plates. A pressure chamber is used around the specimen and lateral pressures are applied in the chamber to the sides of the specimens by gas or liquid. The cylinder forming the sides of the pressure chamber may be made of iron, brass, or a transparent plastic material. While the plastic cylinders are advantageous for inspection of the specimens during the test, volume change under repeated high pressures may require frequent recalibrations. The axial load, which is applied at the bottom or top of the specimen, may be applied manually or by mechanical or hydraulic means, the method of measurement being by a system of levers (scales), proving rings, or by pressure capsules. In most equipment, provisions are made to saturate or drain the specimens during the test, if desired. Axial strain measurements are usually made by dial gages which measure the travel of the axial load piston. Volume change measurements may be made by measuring the water extruded from completely saturated specimens, or by the flow of liquid to or from the pressure chamber.

One of the most common designs for the triaxial compression machine utilizes a platform scale loading device. Such a device, as used at Harvard University, is shown by Figure 43. This laboratory also has a large loading frame (see Section H) to accommodate 12 consolidation or triaxial apparatus with a maximum of 1,800 kilograms on each loading yoke. A Universal loading machine is used here for performing unconfined compression tests and also dynamic compression tests. One pendulum loading device and one hydraulic loading apparatus are also available for the application of dynamic loads to cylindrical soil specimens under triaxial compression.

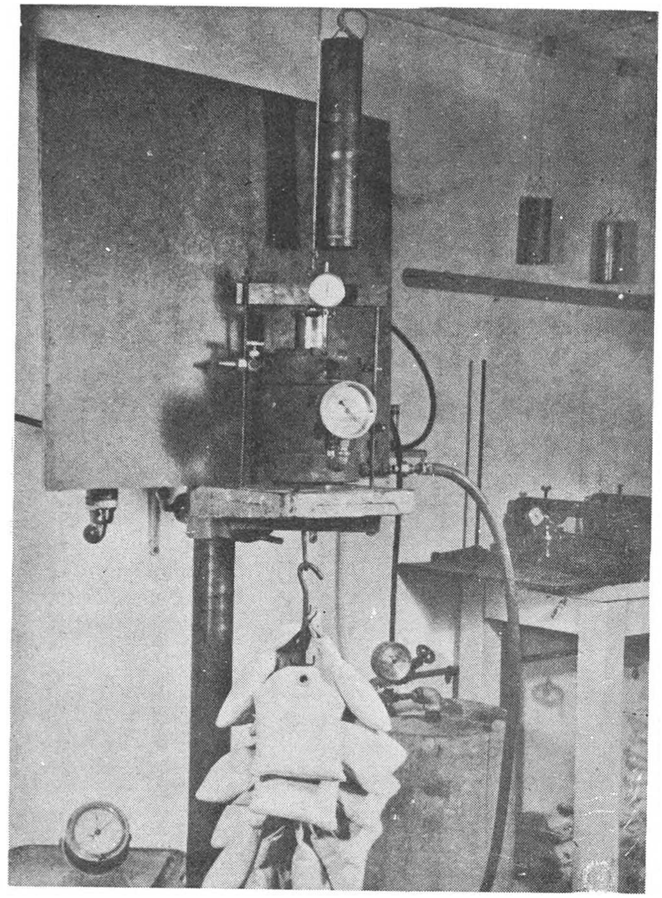
The Waterways Experiment Station, Corps of Engineers, is equipped with one unconfined compression test apparatus that is electrically driven at constant strain, three Universal testing machines, and 17 triaxial compression chambers for specimens 1.4 to 5.6 inches in diameter. A repetitive loading device for 1.4-inch diameter specimens is shown in Figure 44.

Universal testing machines are used in many laboratories for the application of axial loads. A typical setup for the triaxial com-



Triaxial Shear - Specimen Chamber

FIG. 47



Triaxial Shear - Yoke Loading Device

FIG. 48

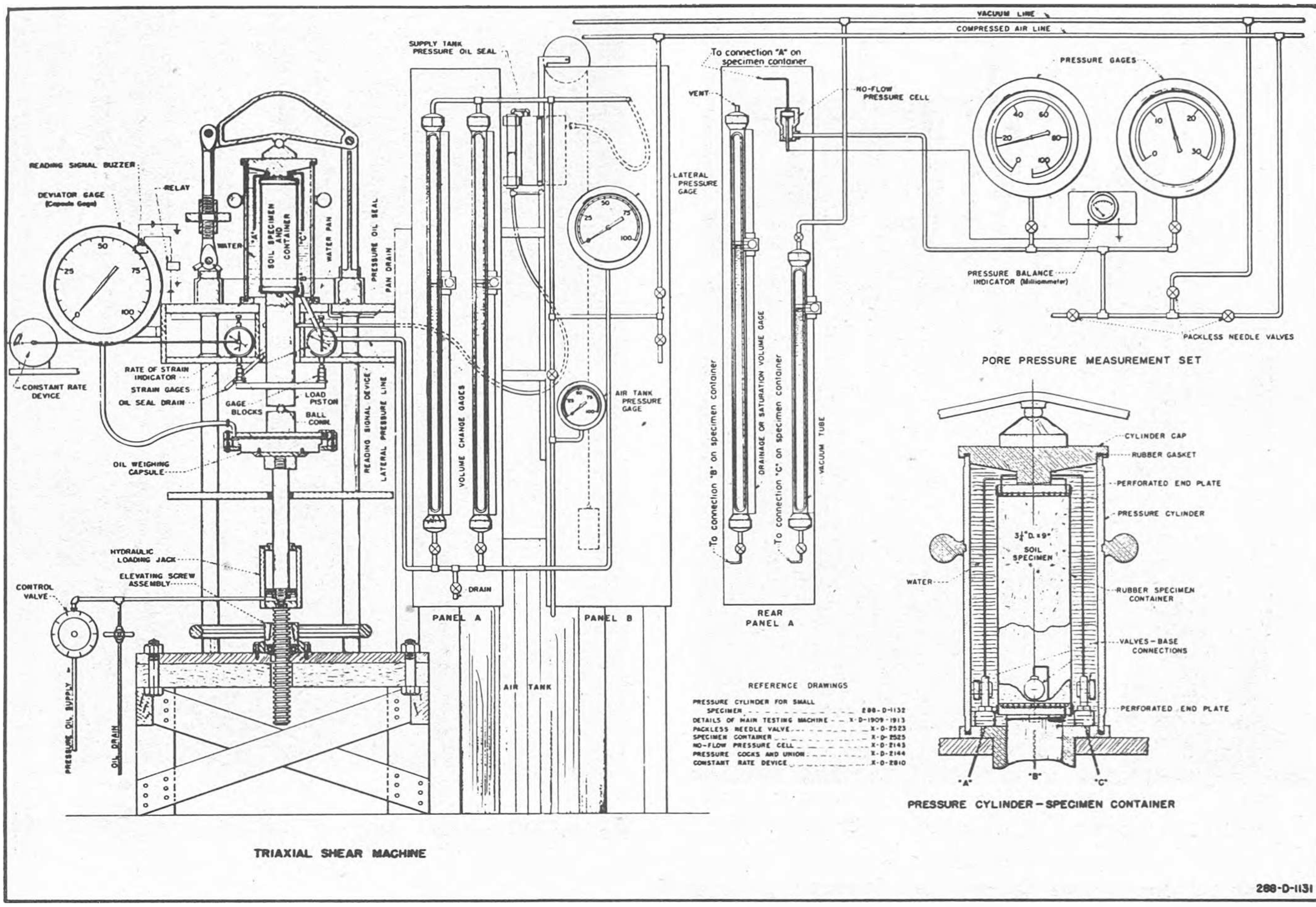
pression test with a Universal testing machine as used by the Kansas State Highway Commission is shown on Figure 45. The stabilometer, as used with a Universal testing machine at the University of Michigan laboratories, is discussed in the manual Laboratory Manual of Soil Testing Procedures by William S. Housel.

The triaxial compression units of the Massachusetts Institute of Technology laboratory are used for testing specimens 1.4 to 2.8 inches in diameter. The axial load is applied by a constant speed motor operating under a strain-control principle, the load being measured by a proving ring inside the pressure chamber as shown by Figure 46. Numerous special devices are provided for measuring pore pressures within the specimens during shear and specimen lengths during test, as well as providing drainage or saturation. Rotary bushings have been devised to reduce piston friction.

The Northwestern University laboratory is equipped with seven units for triaxial compression testing of specimens 1.4 and 2.8 inches in diameter. Equipment for measuring consolidations and pore pressures is described in Paper 3.12.

Two strain-control motor-operated loading machines are used for applying vertical loads with calibrated loading rings of different capacities at the Columbia University laboratory. The normal rate of loading is 0.02 inch per minute. For special slow loading tests the rate of loading can be reduced by steps of 1/10 to a rate of 0.00002 inch per minute. Two triaxial compression test devices, as illustrated in Figure 47, are available with interchangeable porous heads for drainage at both bottom and top of the specimen in sizes of 2.0, 2.5, and 3.0 inches in diameter. The lateral pressure in a lucite pressure chamber is held constant by a very sensitive air-reducing valve and is measured by a mercury manometer for pressures up to 1 kilogram per square centimeter, and a calibrated pressure gage for higher pressures. Vertical displacements are measured by a 1/1000 Ames Dial. Volume changes in the soil specimen are measured through top and bottom drainage outlets by a pipette, which can be read to 1/100 inch with a means for adjusting the water level for any quantity of water to be measured. Pore pressure measurements are made, when desired, by means of a balanced system consisting of a mercury manometer of fine capillary bore and a pressure-vacuum gage with a manually operated pressure device coupled permanently between the manometer and the gage for balancing pressures.

Two types of machines are available at the California Institute of Technology laboratory, varying only in detail of construction. Specimens may be 2.4 inches or 1.4 inches in diameter and up to 6 inches high. The bottom support for the specimen is fixed and is provided with a drain for measuring pore pressure or volume of water extruded. The block which fits on top of the sample is provided with a drain which connects by means of a flexible tube to an opening through the top plate of the machine. The top head of the machine contains a lapped loading piston, so made that it will fall under its own weight, but tight enough so that it will hold air pressure with practically no leaking. Hydrostatic pressure is provided through an accumulator tank by either air or glycerin. The major principal stress is applied by means of a testing machine running at constant speed. Deformations are measured by dial gages attached to the loading piston outside of the pressure chamber. The second type of triaxial shear machine uses specimens of the same diameter as the previously described ma-



Triaxial Shear - Schematic Drawing

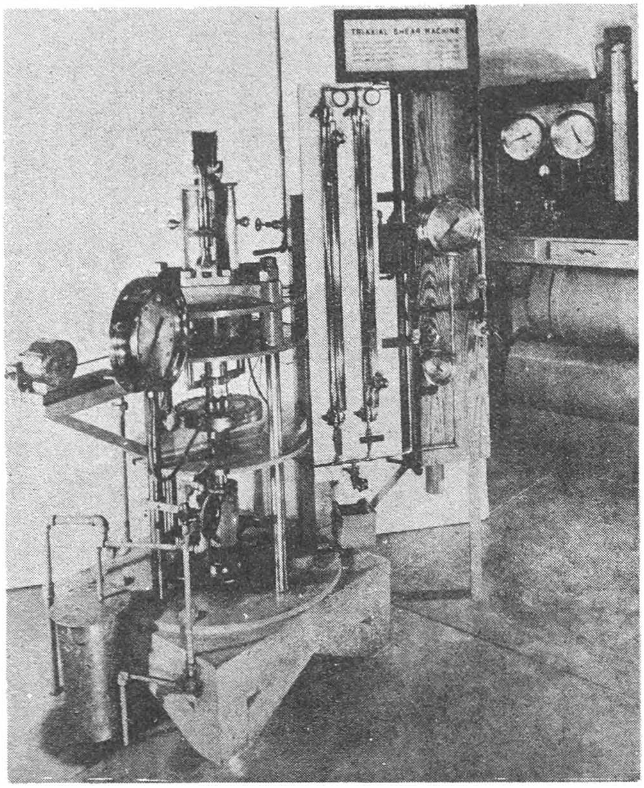
FIG. 49

chine. The load in this case is applied by a hydraulic plunger situated within the base of the machine. The pressure of the plunger is kept constant by dead weights applied to a ground and lapped plunger. Hydrostatic pressure is also kept constant by a ground and lapped piston and dead weight. The top plate contains a screw permitting adjustment according to the height of the specimen. Oil is used in the load plunger, and water in the hydrostatic pressure chamber. Deformations are measured by a device connected to the plunger inside the pressure chamber.

In the triaxial compression tests at the Rensselaer Polytechnic Institute, the vertical load is applied pneumatically. To provide this feature, an air cylinder of the type used in the paper manufacturing industry is utilized. By applying pressure both above and below the piston, the dead weight of the loading yoke may be counter-balanced. Any desired loading within the capacity of the cylinder may be applied by increasing the pressure on one side of the piston. The pressure on the piston is adjusted by operating the regulator which allows air to pass to the cylinder and controls the quantity required to hold the pressure constant at a point set by the regulator. A pressure differential of at least 10 to 15 pounds across the control is found essential for best operation. When these pressures have been set they will remain constant as long as the pressure of the main supply does not drop below the setting of the regulator plus the required differential. For any volume change in the specimen a corresponding displacement of the piston takes place and more air is automatically allowed to pass through the control regulator keeping the load constant.

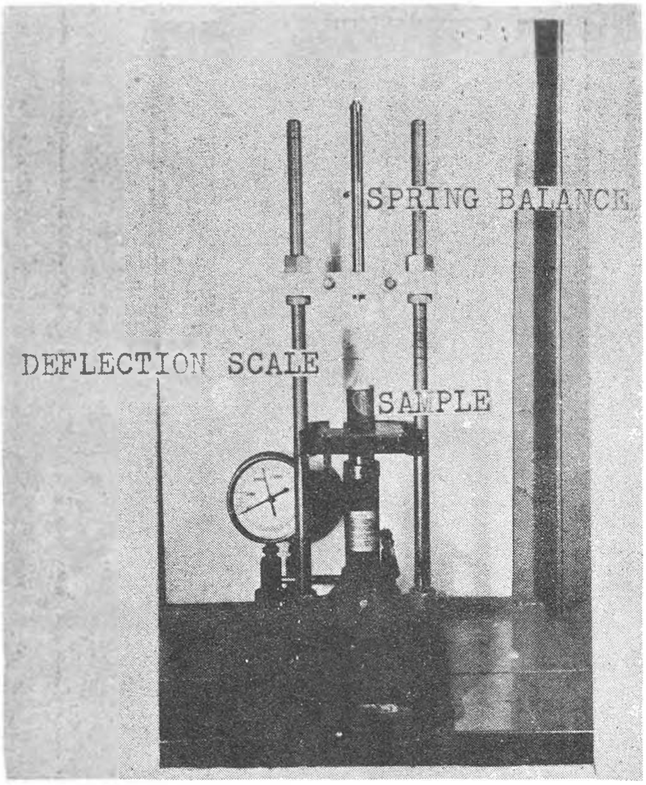
The actual load on the test specimen is measured by the deflection of a previously calibrated proving ring placed between the piston rod and the testing block or apparatus. The line pressure gages are, therefore, used only as a guide in loading, and any friction in the cylinder does not affect the test. The proving rings are made of seamless steel tubing 6 inches in outside diameter. They are of uniform width and are brought to the desired loading range and sensitivity by removing materials from the outside. Specially constructed four piece clamps are placed on the ring and held rigid by alining pins and bolts. The latter does not pass through the ring section. The clamp sections held with the ring forms a mounting for a Federal dial gage which registers the deflection. The outside upper section of the clamp is made to fit over the threaded end of the air cylinder piston rod. The outside lower section is finished in a spherical surface which contacts a similar surface on the top of the loading block. All rings are calibrated by dead weights. Specimens for the triaxial test are 1.4 inches in diameter and 8 inches long. Laterial loading is applied by compressed air. Desired pressure is maintained by control valves as described for the vertical loading.

Triaxial compression tests are made on specimens 1.938 inches in diameter and 4 inches long at the laboratory of the Navy Department,



Triaxial Shear - Hydraulic Loading Device

FIG. 50

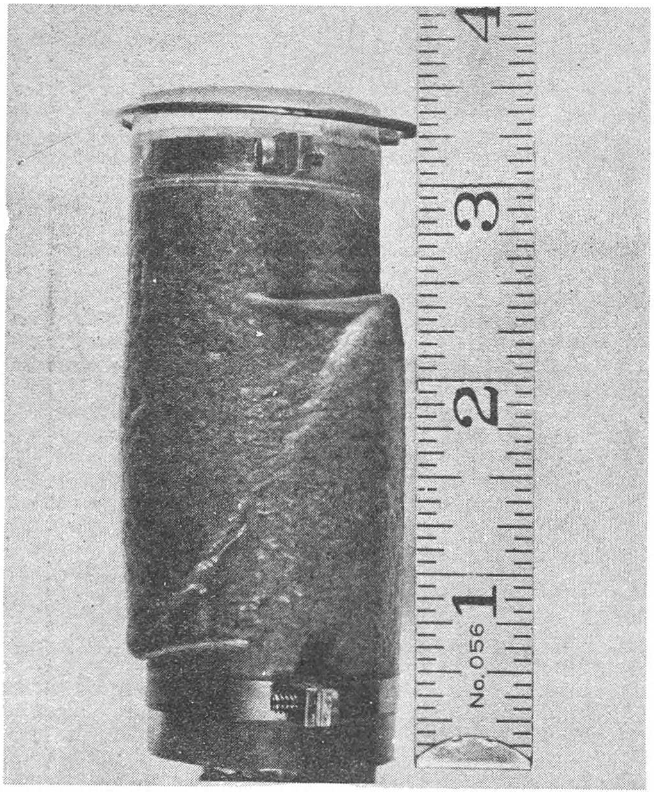


Triaxial Shear - Unconfined Compression Device

FIG. 50 a

Bureau of Yards and Docks. The lateral pressures may be varied from 0 to 20 psi. The rate of strain is not constant. The equipment used at this laboratory is shown on Figure 48.

The Bureau of Reclamation triaxial shear equipment is shown by the drawing, Figure 49, and the photograph, Figure 50. Specimens varying in size from 1-3/8 inches diameter by 2-3/4 inches long to 3-1/4 inches diameter to 9 inches long may be tested. The smaller specimens are used for testing undisturbed samples and the larger specimens are usually used for testing remolded earth materials. The small size allows the cutting of a group of companion specimens from one horizon of a 6-inch diameter soil core. Figure 51 shows a small shear specimen after failure. The specimens are contained in rubber sleeves clamped to perforated metal or plastic and plates. Pore pressure measurements are made through one end plate. Saturation or drainage may be effected during the test, if desired. Lateral pressures up to 100 psi are applied by air pressure on the water surrounding the specimen in a brass pressure chamber. This air pressure is applied on the water in volume change tubes, which are connected to the pressure chamber, the flow of water to or from the pressure chamber being interpreted as specimen volume change. The axial loads are applied hydraulically at a constant rate of axial strain, the axial load being measured through a pressure capsule by a pressure gage. Axial strain measurements are made by dial gages on the load piston. An oil pressure seal is used between the load piston and the base of the pressure chamber. Pore pressures are measured by means of a diaphragm, no-flow, pressure cell. The air pressure used to balance the pore pressure built up in the cell is interpreted as the pore pressure.



Triaxial Shear - Failed Shear Specimen

FIG. 51

BUREAU OF RECLAMATION
EARTH MATERIALS TESTING

SPECIMEN PLACEMENT DATA SHEET

Sheet 1 of 3

Sample No. 00-T8 — Feature: Research

Specimen No. 1 — Date: November 2, 1943

Container No. 1 — Compaction: 25 Blows

		Initial	Final
(1) Wt. Spec. & Cont. - Air	(gm.)	3856.1	3856.1
(2) Wt. of Container - Air - Rubber / Endplate $\frac{60.4}{754.6}$	(gm.)	1280.0	1279.3
(3) Wet Wt. of Specimen = (1) - (2)	(gm.)	2576.1	2576.8
(4) Dry Wt. of Specimen = (3) / $(1 + \frac{(12)}{100})$	(gm.)	2236.2	2236.2
(5) Wt. of Water = (3) - (4)	(gm.)	339.9	340.6
(6) Wt. Spec. & Cont. - H_2O	(gm.)	2376.8	2377.9
(7) Wt. Loss Spec. & Cont. = (1) - (6)	(gm.)	1479.3	1478.2
(8) Wt. Loss of Container	(gm.)	257.5	257.5
(9) Wt. Loss of Specimen = (7) - (8)	(gm.)	1221.8	1220.7
(10) Specimen Volume = (9) / 16.350	(cu. in.)	74.728	74.661
(11) Dry Density = $\frac{(4) \times 62.29}{(9)}$	(lbs./cu. ft.)	114.01	114.11
(12) Moisture, Percent Dry Wt.	(%)	15.20	15.23
(13) Absolute Soil Density = Sp. G. x 62.43(pcf)		171.058	
(14) Soil Volume = (11) x 100 / (13)	(%)	66.65	66.71
(15) Water Volume = (11) x (12) / 62.29	(%)	27.82	27.90
(16) Free Air Volume = 100 - (14) - (15)	(%)	5.53	5.39
(17) Void Ratio = $\frac{100}{(14)} - 1$		.500	.499
(18) Degree of Saturation = $\frac{(15) \times 100}{100 - (14)}$	(%)	83.42	83.81
		Weighed	Measured
(19) Volume Change	(cu. in.)	- 0.07	+ 0.02
(20) Drainage	(cu. in.)		

Prepared by OAN & KC — Computed by KC — Checked by OAN

ED 76-44

BUREAU OF RECLAMATION
EARTH MATERIALS TESTING
TRIAXIAL SHEAR-TEST DATA SHEET

Sheet 2 of 3

Sample No. 00-T8 — Feature: Research

Specimen No. 1 — Date: November 2, 1943

Constant Strain Rate .050 in./min. — Recorder: KC

	Time Actual	Gage Lateral Press.	Deviator Gage Read	Axial Strain: Dial	Axial Strain: Strain	Volume Change: Tube 1	Volume Change: Tube 2	Drain. Tube: Read.	Drain. Tube: Volume	Absolute Pore Press.
		psi	psi	Inches					cu. in.	psi
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0	0	1.4	.075		1.00				12.8
2	1	100.0	13.2	.075		11.95				60.8
3	5	12.2 / 112.2	13.2	.075		12.29				65.0
4	15	(Absol.)	13.2	.075		12.43				67.2
*5	16		13.2	.224	.149	10.06				67.7
*6	18-0		13.2	.224		30.00				67.7
7	1.5		17.1	.3	.076	29.10				81.2
8	3.5		19.6	.4		27.80				88.7
9			21.0	.5		26.36				93.4
0			21.9	.6		24.89				95.7
1			22.6	.7		23.39				96.5
2			23.2	.8		21.89				96.9
3			23.8	.1		20.35				96.8
4			24.3	.2		18.82				96.3**
5			24.8	.3		17.27				95.7
6			25.2	.4		15.78				95.0
7			25.6	.5		14.25				94.2
8			26.1	.6		12.69				93.4
9			26.5	.7		11.14				92.6
0			26.8	.8		9.57				92.0
1			27.3	.1		7.97				91.1
2			27.4	.2		6.39				90.7
3			27.7	.3		4.79				89.9
4			28.0	.4		3.19				89.2
5			28.3	.5		1.60	30.00			88.6
6			28.5	.6			28.44			87.9
7			28.6	.7			26.88			87.2
8			28.8	.8			25.34			86.0
9		0.0	1.4	.3			21.21			11.9
0										

*Specimen just touching stop. **Point of Maximum Principal Stress Ratio.

Form No. ED 54-41 — Initial Temp. 72°F. Final Temp. 71.7°F.

BUREAU OF RECLAMATION
EARTH MATERIALS TESTING
TRIAXIAL SHEAR-TEST COMPUTATION SHEET

Sheet 3 of 3

Sample No. 00-T8 — Feature: Research

Specimen No. 1 — Date: November 2, 1943

	Tube Change	Piston Change	Corr.	Volume Change	Volume	Length	Mean Area	Deviator: Load	Deviator: Stress	Axial Strain	Volume Change	Drainage
	Cubic Inches					Ins.	sq. in.	lbs	psi	%	%	%
	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
1	.00				74.73							
2	-3.74		+.32	-3.42	71.31							
3	3.86		"	3.54	71.19							
4	3.91		"	3.59	71.14							
5	3.09	-.81	"	3.58	71.15	8.876					-4.79	
6	.00											
7	+.32	-.41	+.01	-.08	71.07	8.8	8.08	189	23.4	.86	-4.90	
8	.78	.95	.02	.15	71.00	.7	8.16	310	38.0	1.98	4.99	
9	1.30	1.49	"	.17	70.98	.6	8.25	378	45.8	3.11	5.02	
0	1.82	2.03	"	.19	70.96	.5	8.35	422	50.5	4.24	5.04	
1	2.35	2.58	"	.21	70.94	.4	8.45	456	54.0	5.36	5.07	
2	2.89	3.12	"	.21	70.94	.3	8.55	485	56.7	6.49	5.07	
3	3.44	3.66	"	.20	70.95	.2	8.65	514	59.4	7.62	5.06	
4	3.98	4.20	.03	.19	70.96	.1	8.76	538	61.4	8.74	5.04	**
5	4.53	4.74	"	.18	70.97	8.0	8.87	563	63.5	9.87	5.03	
6	5.06	5.28	"	.19	70.96	7.9	8.98	582	64.8	11.00	5.04	
7	5.59	5.82	"	.20	70.95	.8	9.10	601	66.0	12.12	5.06	
8	6.13	6.36	"	.20	70.95	.7	9.21	626	68.0	13.25	5.06	
9	6.67	6.90	"	.20	70.95	.6	9.34	645	69.1	14.38	5.06	
0	7.22	7.44	"	.19	70.96	.5	9.46	660	69.8	15.50	5.04	
1	7.77	7.99	"	.19	70.96	.4	9.59	684	71.3	16.63	5.04	
2	8.30	8.53	"	.20	70.95	.3	9.72	689	70.9	17.76	5.06	
3	8.84	9.07	"	.20	70.95	.2	9.85	703	71.4	18.88	5.06	
4	9.39	9.61	"	.19	70.96	.1	9.99	718	71.9	20.01	5.04	
5	9.93	10.15	"	.19	70.96	7.0	10.14	732	72.2	21.14	5.04	
6	10.47	10.69	"	.19	70.96	6.9	10.28	742	72.2	22.26	5.04	
7	11.02	11.23	"	.18	70.97	.8	10.44	747	71.6	23.39	5.03	
8	11.55	11.77	"	.19	70.96	.7	10.59	757	71.5	24.52	5.04	
9	12.99	9.07	-.32	+3.60	74.75							
0												

**Point of Maximum Principal Stress Ratio.

Form No. ED 55-41 — Computer KC — Checker OAN

BUREAU OF RECLAMATION
EARTH MATERIALS TESTING

TRIAXIAL SHEAR TEST
LEAST SQUARES COMPUTATION SHEET

Sample No. 00-T8 — Project:

Date: October 10, 1945 — Feature: Research

Spec. No.	σ_1	σ_3	$\sigma_1 + \sigma_3$
9	37.8	4.7	42.5
3	54.5	9.1	63.6
2	65.6	12.5	78.1
1	77.3	15.9	93.2
Σ	235.2	42.2	277.4
M	58.80	10.55	69.35
Ext. σ_1	$\Sigma(\sigma_1)^2$ = 14,677.74	$\Sigma(\sigma_1 \times \sigma_3)$ = 2,722.68	$\Sigma\sigma_1(\sigma_1+\sigma_3)$ = 17,400.42
Corr.	$M_1 \times \Sigma\sigma_1$ = 13,829.76	$M_1 \times \Sigma\sigma_3$ = 2,481.36	$M_1 \times \Sigma(\sigma_1+\sigma_3)$ = 16,311.12
np^2	(1) = 847.98	(2) = 241.32	(3) = 1,089.30
Ext. σ_3	$\Sigma(\sigma_1 \times \sigma_3)$ = 2,722.68	$\Sigma(\sigma_3)^2$ = 513.96	$\Sigma\sigma_3(\sigma_1+\sigma_3)$ = 3,236.64
Corr.	$M_3 \times \Sigma\sigma_3$ = 2,481.36	$M_3 \times \Sigma\sigma_3$ = 445.21	$M_3\Sigma(\sigma_1+\sigma_3)$ = 2,926.57
np^2	(4) 241.32	(5) 68.75	(6) 310.07
$\sqrt{n}\,p$			

$\gamma^2 = (2)/(5) =$ 3.51011

$\gamma =$ 1.873529 $2\gamma =$ 3.747058

$2C\gamma = M\sigma_1 - \gamma^2 M\sigma_3 =$ 21.77

$C =$ 5.81

$\tan\phi = \frac{\gamma^2 - 1}{2\gamma} =$ 0.67

ED 78-45

Triaxial Shear - Data Sheets

FIG. 52

Figure 50a shows the unconfined compression machine used by the Knappen Engineering Company.

3. Test Procedure

The procedures for conducting the triaxial compression test vary considerably in different laboratories in conformance with the different types of equipment used and the different concepts of triaxial compression test results. Because of the wide variation in procedures and techniques as practiced in the United States, only a brief, general procedure is given herein.

a. Apparatus

1) Specimen preparation. For the preparation of undisturbed specimens, a cylindrical ring soil cutter is usually provided. This cutter is sharpened on the outside and is of the same diameter as the soil specimen desired. In cases where a cutting bit is used, the cutter barrel may be slightly larger than the bit. The cutting equipment usually includes a device for holding the sample and cutter and produces a controlled axial movement of the cutter. A compaction cylinder, of the same diameter as the specimen, is usually provided for preparing remolded specimens. Manual or mechanical compaction hammers are used. Instruments such as knives, spatulas, wire saws, etc., are used for trimming the specimens.

2) Specimen container. Rubber sleeves; end plates made of solid metal or plastics, perforated metal or plastics, porous stones or porous bronze; clamps or rubber bands for holding the sleeve to the end plates; tubes, valves, etc. for connection to end plates for saturation, drainage, or pore pressure measurement.

3) Compression chamber. A compression chamber suitable for applying liquid or gas pressure to the soil specimen with suitable measuring devices. See Paragraph 2 for various types.

4) Loading device. A device suitable for applying axial load to the soil specimen. These may be manual, mechanical, or hydraulic as discussed in Paragraph 2. The loading device is usually controlled for constant stress or constant strain and includes suitable measuring devices for load and strain.

5) Miscellaneous equipment. Other equipment usually provided, as indicated in Paragraph 2, include specimen volume measurement apparatus, volume change measuring devices, drainage and saturation devices and pore pressure measuring equipment.

b. Specimen Preparation

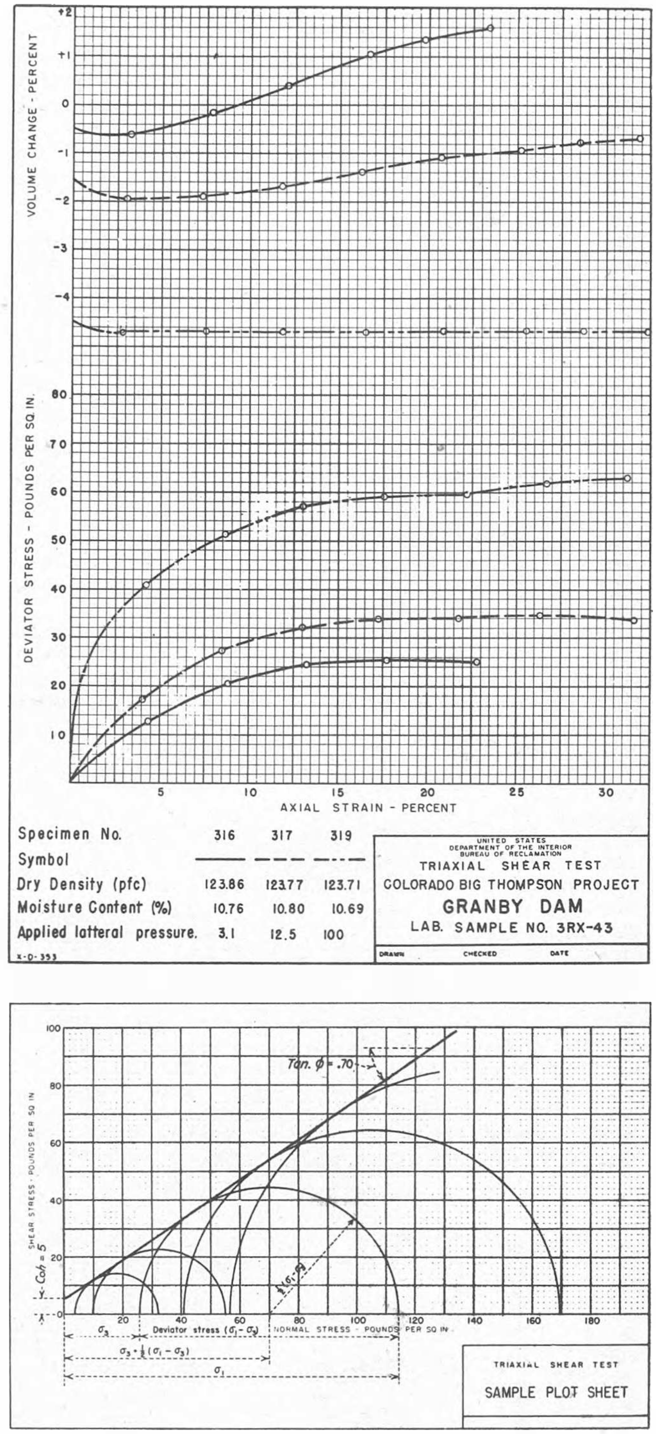
1) Preparation of disturbed or remolded specimen. Sufficient soil to fill the specimen mold is compacted, compressed, or vibrated into the container to the required height. The compaction is usually performed on several layers of soil. An extension collar is usually provided, and the excess soil is trimmed to the required specimen height. Remolded specimens are accurately controlled to desired moisture and density conditions.

2) Preparation of undisturbed specimen. The soil cutting bit is placed over the soil sample and the material is trimmed with a knife close to the cutting bit, leaving very little material for the bit to shave off as it is gently pressed downward. The ends of the specimen are trimmed to the correct height. Initial moisture determinations may be made from the trimmings, or, if a sealed test is conducted, on the entire specimen.

c. Testing

1) The prepared specimen is placed in the rubber sleeve and the sleeve clamped to the end plates, after which the assembly is placed in the pressure chamber and appropriate connections are made to the end plates for saturation, drainage, or pore pressure measurements. Pilot tubes may be inserted into the specimen for pore pressure measurement. The chamber is filled with a liquid, such as water or glycerin, and sealed, after which pressure is applied to the liquid. In some cases the pressure is applied around the specimen by a gas medium. Preconsolidation, prior to shear

50a



Triaxial Shear - Curve Sheets

FIG. 53

testing, under applied lateral or applied lateral and axial loads is usually desirable. Saturation or drainage may be carried out during the preconsolidation period. The technique and method used in preconsolidating a specimen will depend upon the problem, the material, and the interpretation of the test data. After the application of the lateral (chamber) pressure, and after any preconsolidation period, the axial load is applied under controlled strain or controlled stress conditions until failure occurs. Many institutions consider the maximum deviator stress (unit axial stress applied in excess of the chamber pressure) to represent the point of incipient failure for triaxial compression test specimens. The Bureau of Reclamation recognizes the point of maximum principal stress ratio as the incipient failure point. (This criterion which was established for tests involving pore pressure corrections, allows for the effect of pore pressure in producing variable effective lateral stresses even though constant lateral pressures are applied during the test). Further loading, after failure, may be desirable in some cases. The axial load may be applied rapidly so as to produce a "quick" shear condition or slowly to produce a "slow" shear condition. If a drained test is being conducted, it may be desirable to load the specimen at a rate of volume change commensurate with the rate of drainage to allow a zero pore pressure condition to exist throughout the specimen. Here again the techniques vary considerably with the material being tested, the problem and interpretation of the data. At frequent intervals during the application of lateral and axial loads, the following information is usually obtained: total volume change, axial deformation, applied axial load, applied lateral pressure, drainage--if pertinent, and pore pressure measurements--if desired. After completion of loading, final measurements of volume change, unit weight, moisture, etc., may be obtained as desired. The test procedures must include the use of many correction factors that are determined by calibration tests on the equipment. Many worthwhile forms have been prepared by several institutions for recording the test data. These forms vary, depending upon the data obtained and the method of analysis. As an example, the forms and plot sheets used for this purpose by the Bureau of Reclamation are included as Figures 52 and 53.

Various detailed test procedures may be found in the folowing publications: Progress Report on Triaxial Shear Research and Pressure Distribution Studies on Soils--War Department, Corps of Engineers, in cooperation with Harvard University, Massachusetts Institute of Technology, and the Waterways Experiment Station; Procedures in Soil Testing--American Society for Testing Materials; Laboratory Manual of Soil Testing Procedures--Michigan University; Notes on Soil Testing for Engineering Purposes--Harvard University; Laboratory Procedure in Testing Earth Materials for Foundation and Construction Purposes--U.S. Bureau of Reclamation.

K. MISCELLANEOUS TESTING

1. General

Many special types of tests and laboratory equipment have been developed throughout the United States for solving individual or special soil problems. Several of these specialized tests are discussed in the following paragraphs.

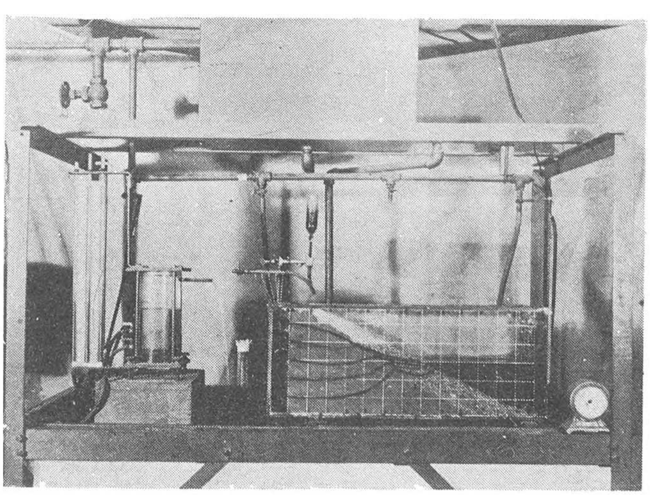
2. Soil Stabilization

The stabilization of soils by mechanical, physical, and electrical means is studied at many laboratories. Most State Highway Departments, as well as the Bureau of Reclamation, the Massachusetts Institute of Technology, the Texas Technological College, the University of South Carolina, Rensselaer Polytechnic Institute, and Princeton University, are equipped to conduct tests on the stabilization of soil with bitumens and cement. The Portland Cement Association has pioneered in the development of soil stabilization with cement. Electrical and chemical methods of soil stabilization are studied at Princeton University and the Rensselaer Polytechnic Institute.

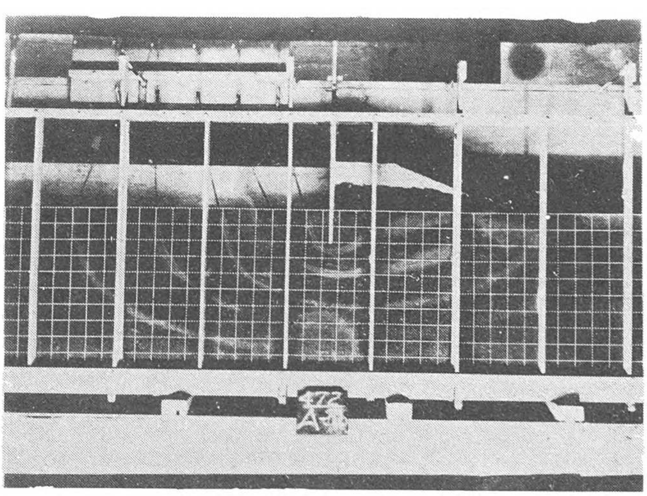
3. Seepage

The study of seepage through earth dams, filters, and other structures is made in several laboratories by means of model studies conducted in seepage flumes.

Columbia University has a two-unit stand equipped with a constant head tank containing a sand filter bed for removing a large part



Small Seepage Flume
FIG. 54



Portion of Large Seepage Flume
FIG. 55

of the air from tap water, which is to be used for permeability and seepage tests. A small seepage flume (Figure 54) 30 inches by 12 inches by 4 inches is used for studying and demonstrating flow patterns for entrance, interface, and emergence conditions of flow through soils in various structures. The flume is equipped for flow in either direction with adjustable head and tail water elevations, and pipettes for introducing dye stream lines. A large seepage flume 100 inches by 32 inches by 8 inches is used for more detailed studies of flow and potential patterns for special problems of seepage through earth dams, cofferdams, and tunnels. The flume is equipped with a bank of manometers at three elevations for determining the potential field, and with pipettes for introducing dye stream lines. A portion of this large flume is shown in Figure 55.

The Waterways Experiment Station at Vicksburg has the seepage flume shown in Figure 56.

A seepage flume used at the Rensselaer Polytechnic Institute is made up of an 8-inch shipbuilding channel, steel angles, 1/8-inch sheet steel and 1/4-inch plate glass. The shipbuilding channel forms the bottom; the sheet steel covers the ends and the back. The glass placed in a steel frame forms the front. The inside dimensions are 8 inches wide, 36 inches deep, and 12 feet long. For ease of operation, and when conditions permit, the glass front may be replaced by another set of 3 glass plates, each 4 feet by 24 inches high. By use of fine screems, clear wells are provided at either end. Three openings, one in each end and one at the center are provided through the channel for the influent and/or the effluent.

The flow line in the flume is controlled by two water level control boxes mounted on parallel rods fastened to the wall at either end of the flume. Each control box has a central overflow pipe, and an inlet and outlet. Filtered water, the temperature of which may be controlled,may be supplied through the control box at any of the inlets. The control boxes may be set on the rods to produce any desired gradient. Piezometer tubes mounted on a wall board are connected to the sheet steel which forms the back of the flume and records the water level within the earth structure that is being considered. This flume has proven to be very useful and flexible in seepage study, well point operation, and for the demonstration and study of cofferdams.

A glass tank or trough approximately 3 feet by 4 feet by 4 inches deep is provided with suitable electric equipment to locate the equipotential lines of flow nets.

A filter box, used by the Connecticut State Highway Department for testing underdrain material, consists of a wooden box, 24 inches long by 16 inches wide by 18 inches high. A 5-inch Lucite tube with 1/2-inch perforations runs through the box near one side. A 60-mesh brass screen is placed for the length of the box near the opposite side and parallel to the tube. Filter material is placed over and around the pipe. Soil is placed between the filter material and the screen. Water is admitted into the "forebay" area on the other side of the screen. When the end of the pipe (tube) is open, water flows through the soil and the filter material, into the pipe perforations. A moderate hydraulic gradient is used and "piping" of the soil, due to the voids of the filter material being too large, can be observed if it occurs.

A filter apparatus for establishing the gradation of materials for filters in earth dams, etc., as used by the Bureau of Reclamation, is shown in Figure 57.

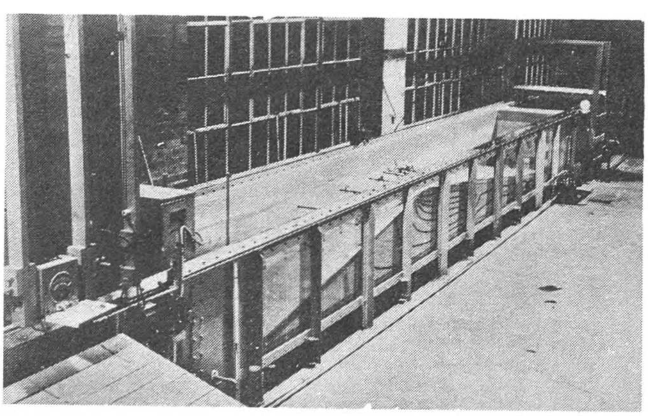
4. Photoelastic Studies

Photoelastic studies of the stresses in foundations are made at the Pennsylvania State College, University of Notre Dame, Ohio River Division of the Corps of Engineers, and the Bureau of Reclamation.

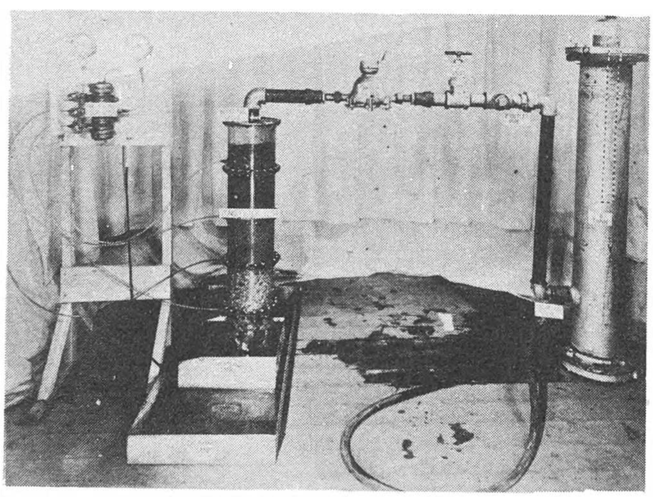
The procudure used at the University of Notre Dame for this test involves making a model of a structure, such as a retaining wall, using gelatin to represent the soil and cement mortar, wood, steel, plastic, etc. to represent the structure applying load to the soil. By placing the model in the polariscope, the maximum shearing stresses caused in the foundation by any load on the structure can be read directly and by using the polariscope to locate the isoclinics, all of the stresses in the foundation can be computed. By using a stress - optically sensitive plastic for the structure, it would be possible to determine the stresses in the structure for the same load.

5. Field Bearing

General. The field bearing test measures the displacement resistance of surfaces, subgrades, or base coarses for stability analysis of existing features and design of rigid pavements for airports and highways. Essentially the test consists of subjecting the prepared



Large Seepage Flume
FIG. 56



Filter Apparatus
FIG. 57

field test section to uniformly increasing load increments on a rigid circular plate representing expected load conditions. Periodic settlement readings are taken. The test is performed on the undisturbed material if compaction is not practicable, or on material compacted to optimum moisture-density conditions. Although testing in the more critical saturated condition is derired, it is mot generally practicable, so that the relation between optimum and saturated conditions is obtained by standard consolidation tests performed on representative soil samples in the laboratory.

Field bearing test equipment varies throughout the United States only in the size of the bearing plates, the detail of loading apparatus and in interpretation of results for design purposes.

The detailed test procedure used by the U.S. Army Engineers may be found in the Engineering Manual, Chapter XX, Part IV.

Testing Equipment. The U.S. Army Engineers perform the field bearing test by loading a bearing plate 30 inches in diameter with a hydraulic jack placed under heavy construction equipment. A ball joint prevents eccentricity of loading.

The Minnesota Highway Department uses a 10,000-pound capacity bearing test machine made by suspending an 8-ton hydraulic jack beneath a truck frame. A ball joint is provided to prevent load eccentricity and piston extensions make possible testing below the road surface. Plates of 6-inch and 12-inch diameters are used.

The Iowa State Highwey Commission employs a unique device for measuring the displacement resistance of subgrades and base courses. A penetrometer attached to a hydraulic jack is forced into the test area from an ordinary post auger hole. Figure 58 shows the apparatus, including the penetrometer attached to jack and base plate, and the device for delivering hydraulic fluid through the flexible line at a constant velocity. Figure 59 shows the device in place ready for testing. The force required to produce penetration is measured by a pressure gage in the hydraulic system.

Field Bearing Test Procedure

a. Apparatus

1) Loading device. Trucks or other suitable heavy construction equipment so adapted that the desired load may be obtained by jacking.

2) Jacks. Hydraulic or other suitable jack of sufficient capacity to transmit the desired load to the test section.

3) Bearing plates. Rigid circular bearing plates of the desired size depending on the tire imprint area of the heaviest vehicle to which the road or runway may be exposed.

4) Deflection measurement device. Extensometers with supports, so that downward movement of the plate can be measured.

5) Additional equipment such as that required for field densities, moisture determinations, etc.

b. Test Section Preparation

The test is made on the surface or base course during or after construction in its existing state. For design, test sections of undisturbed or recompacted materials are constructed as desired to represent the prototype. A section is cleared and leveled carefully and a thin layer of fine, dry sand (not more than 0.25 inch thick) is laid down to give uniform bearing to the plate.

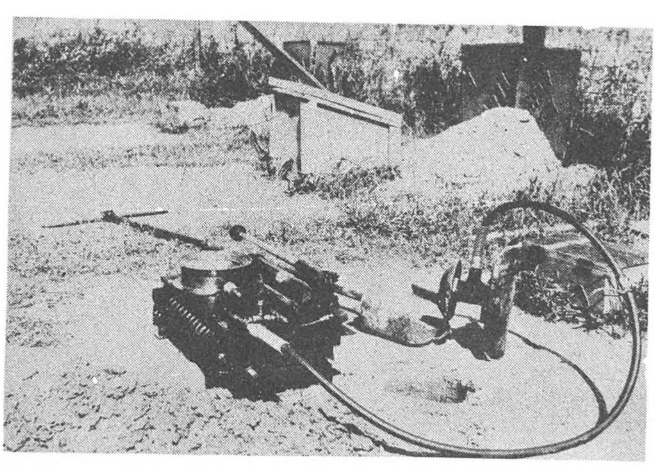
c. Testing

Moisture and density samples are taken to determine the condition of the material in place and the loading equipment is carefully set up and leveled over the test section. A seating load, generally 5 pounds per square inch, is applied and released before the actual test begins. The test load is applied in increments, generally 5 pounds per square inch, allowing practically complete deformation for each increment before another is applied. The test should be continued beyond the "yield point" of the material, or to a loading approximately $1\frac{1}{2}$ times the contact pressure of the heaviest vehicle to which the section will be subjected.

Laboratory consolidation tests are performed on representative samples from the test sections described above to determine the relation between the stability as determined under optimum conditions and the stability under saturated conditions. The soil for Test No. 1 is placed in the consolidometer at conditions similar to field testing conditions. The soil for Test No. 2 is placed in the same manner as the first, after which it is saturated and tested.

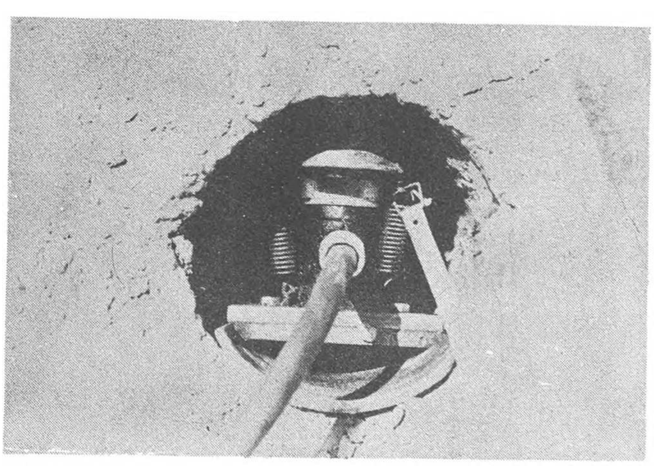
d. Plotting

The results of the field bearing test should be prepared in the form of load-deformation curves, plotting load intensity in



Field Bearing - Penetrometer Apparatus

FIG. 58



Field Bearing - Penetrometer Test

FIG. 59

pounds per square inch against vertical deformation in inches.

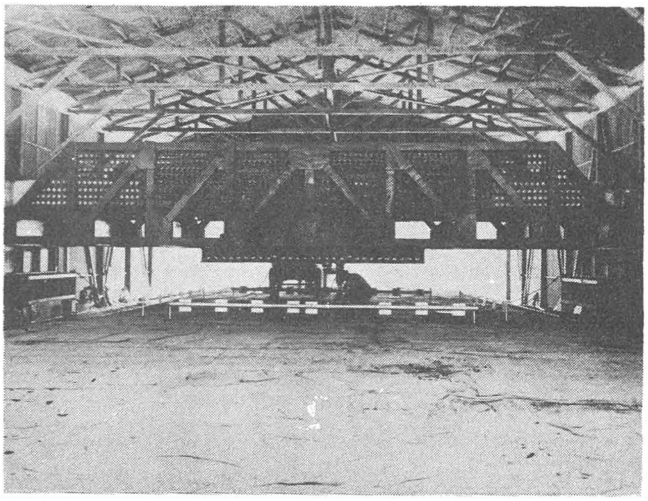
The results of consolidation tests Nos. 1 and 2 should be plotted to show the relation between load intensity and the vertical deformation. This relation, then, can be applied to the field bearing test curves to obtain the approximate values for material in the saturated condition.

6. Stress Distribution Equipment

The Waterways Experiment Station is conducting a research study on stress and strain distribution in soils and flexible pavement structures. A test section has been constructed which is approximately 32 feet wide by 50 feet long. The soil in situ is excavated to a depth of about 8 feet, and a 1-foot sand subdrain and 10 feet of a uniform clayey silt is placed in and above this excavation. Pressure cells are installed in one horizontal plane in the back fill and placed horizontally, vertically, and on 45 degree planes. Deflection gages for the measurement of vertical displacements under loads are also placed in the backfill. Testing procedure consists of the measurement of pressures and deflection beneath single and dual loads on various magnitudes and at various dual plate spacings. Measurements are taken at offset distances such that profiles of the pressures and deflection are obtained in several directions, thus furnishing a complete pattern of induced stresses and strains beneath single and dual loaded plate systems. The variation of pressures and deflections with depth is determined by removing incremental layer of fill from the test section and repeating the entire series of tests at each new elevation.

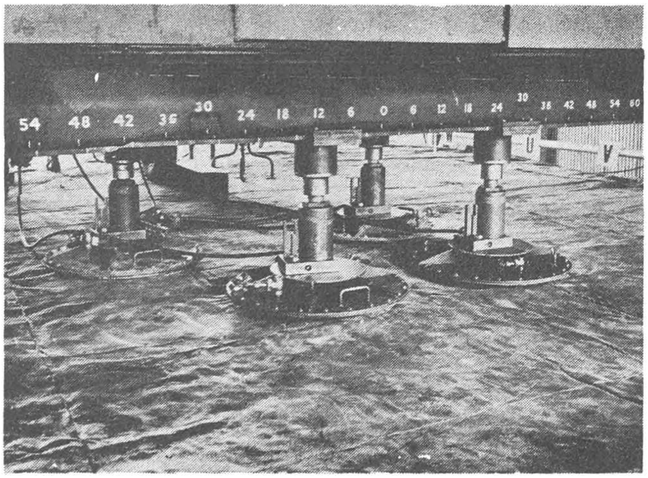
Three items of special equipment used in this study are: 1) a flexible face loading plate, 2) a hydraulic jacking device for the simultaneous application of loads to multiple plate systems, and 3) a loading truss used as a reaction to the multiple jacks outlined in 2). These pieces of equipment are described in the following paragraphs.

Loading Plate. A flexible face loading plate has been developed by the Waterways Experiment Station for the application of a uniformly-distributed circular load. The plate is composed of three principal parts, as follows: 1) a reinforced steel plate, 2) a 1/8-inch circular piece of sheet rubber, and 3) a locking and retaining ring. The steel plate contains two globe valves attached to nipples which are tapped through the steel plate. By means of these valves, water may be introduced between the steel plate and the rubber diaphragm, and at the same time the entrapped air may be bled out. The locking ring attaches the rubber diaphragm of the steel plate. The locking ring also contains a vertical rim about 1/4 inch thick and 1 inch high, knife-edges around the bottom, which serves as a retaining ring to prevent the rubber diaphragm from squeezing



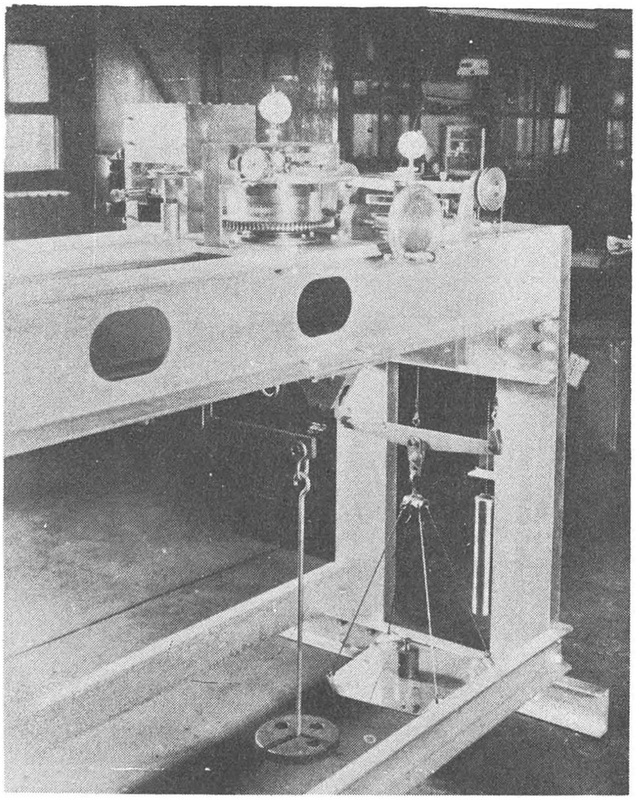
Stress Distribution Loading Truss

FIG. 60



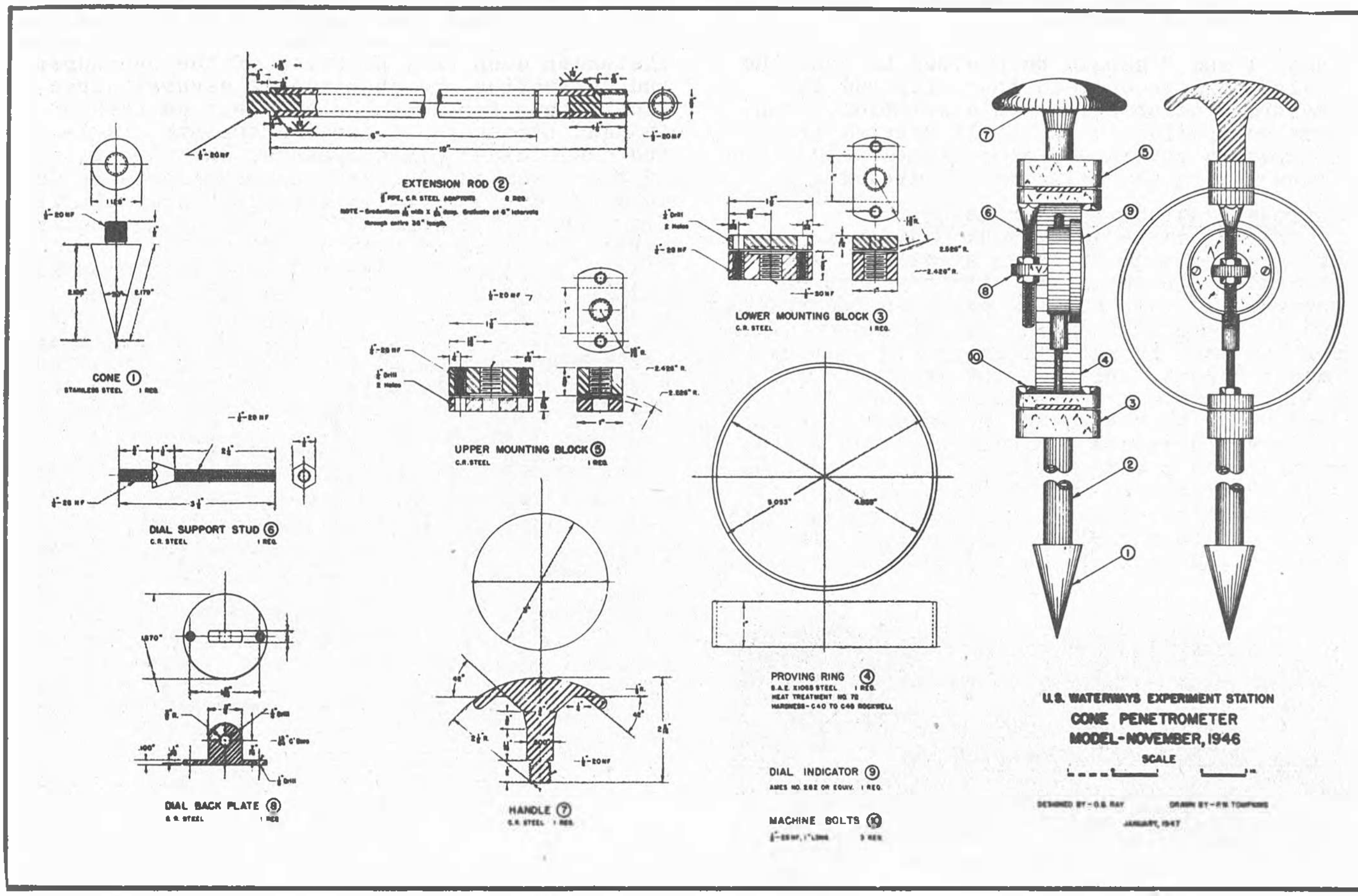
Stress Distribution Load Plates

FIG. 61



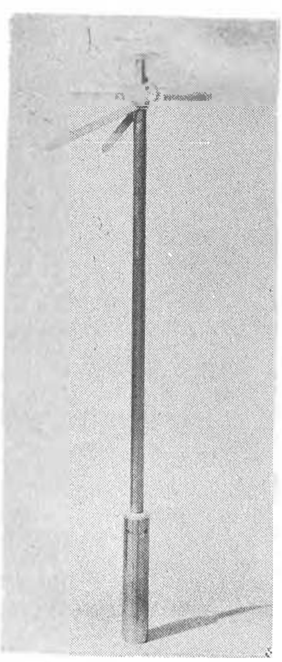
Torsional Shear Machine

FIG. 62



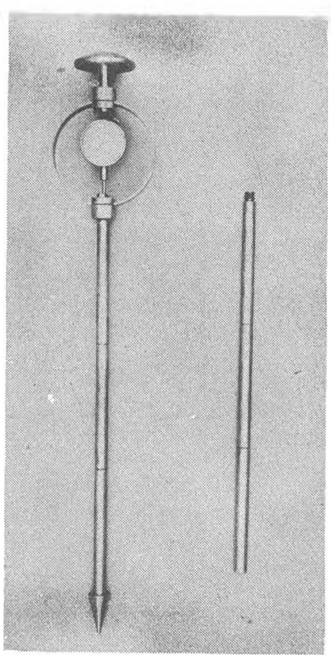
Cone Penetrometer - Details

FIG. 63



Cone Penetrometer Assembled

FIG. 64

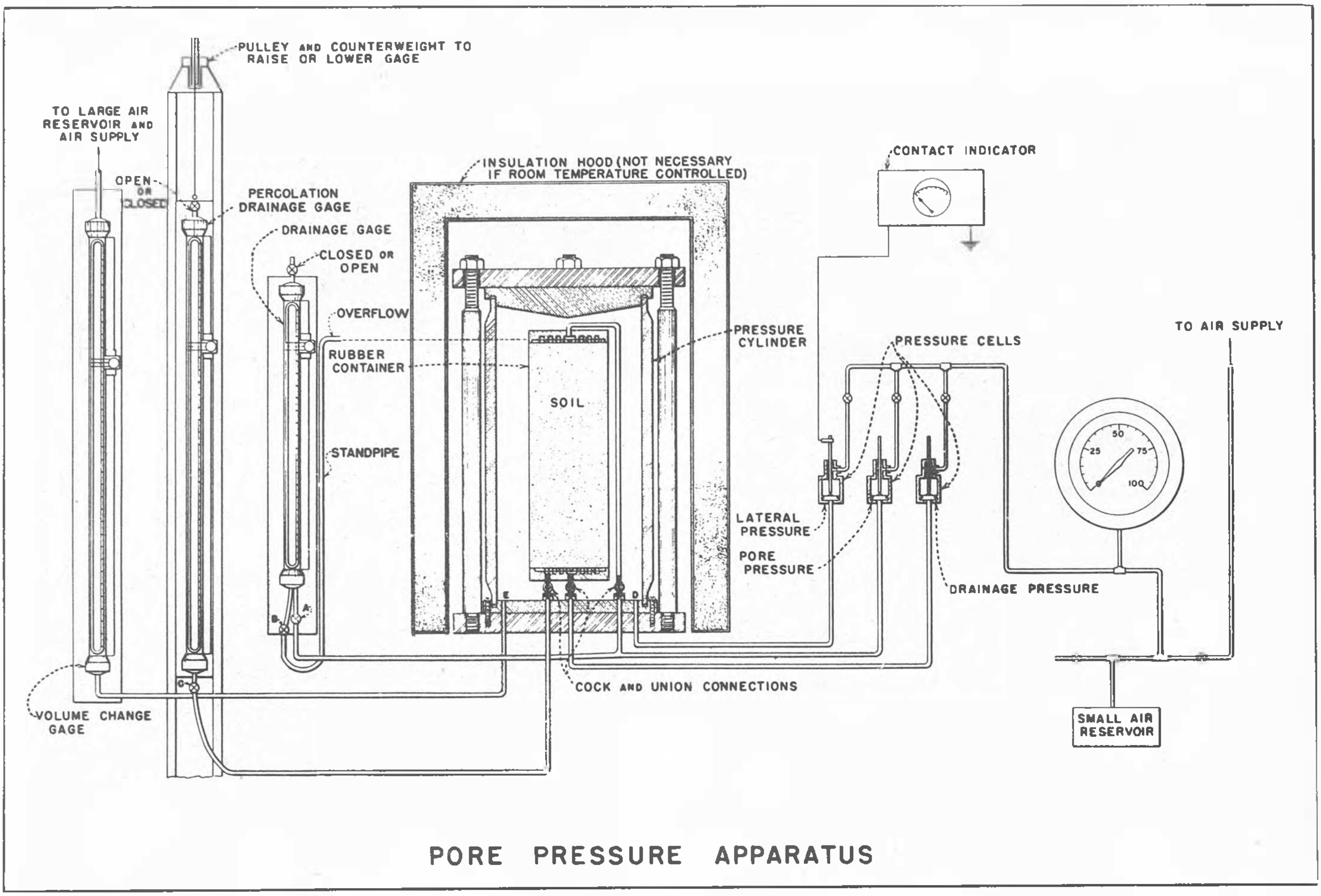


Trafficability Sampler

FIG. 65

out from beneath the plate and confining the diaphragm to a predetermined area. Sufficient water is introduced between the steel plate, and rubber diaphragm such that the vertical or confining portion of the locking ring does not quite touch the soil during load application. Two sizes of plates are presently in use, one giving a circular contact area of 500 square inches and the other giving a circular contact area of 1,000 square inches. Very little trouble has been experienced in the use of these plates to date, and it is considered that they are satisfactory for the application of uniform loads.

Hydraulic jack. In the current stress and strain distribution studies being made by the Waterways Experiment Station, it was desirable to provide a means whereby equal loads would be applied and maintained on as many as four plates simultaneously. A high-pressure hydraulic pumping device was constructed for this purpose. This pumping device consists of a hollow steel block on which are mounted: 1) four hydraulic pumping rams, 2) separate valve-controlled outlets to each hydraulic jack, 3) intake lines from the oil supply reservoir to each pumping ram, 4) a valve-controlled bypass to the oil supply reservoir, and 5) low and high pressure hydraulic gages. The pumping device is electrically driven and employs a cam shaft giving the proper stroke to four



Three Dimensional Consolidation - Test Apparatus

FIG. 66

connecting rods which are attached to the pumping rams. One pressure gage is equipped with an electrical cutout switch, such that when a predetermined maximum pressure is reached the current supply to the motor is automatically stopped.

Truss. Reactive forces for the application of load in the current study are furnished by a truss shown in Figure 60. This truss is basically of a bridge type which is supported at each end on movable carts, which in turn are on rails running along each side of the test section. Two movable beams are attached to the underside of the truss. A detailed view of the truss, Figure 61, shows the arrangement of flexible-face plates and jacks in place for test. These movable beams are fitted with clamps such that they can be placed at any location, either parallel or perpendicular to the axis of the truss. Movable plates are attached to the bottom flanges of the beams and a spacer of extra-heavy pipe and a ball joint is inserted between the jack and the movable plate.

7. Shear.

The Soils Division at the Waterways Experiment Station is now in process of running repetitive triaxial tests, but no standardized procedure has been developed. (See Figure 44). Some samples have been given over 140,000 cycles of loading. Torsion shear tests are being initiated, with Dr. M. Juul Hvorslev as consultant, but testing has not progressed sufficiently to warrent detailed discussion. Figure 62 is a photograph of the torsion shear apparatus.

8. Trafficability of Soils - Test Equipment

One of the principal investigations currently assigned to the Soils Division of the Waterways Experiment Station is the development of methods of evaluating soils with respect to their ability to support the movement of military vehicles. Several instruments have been developed in the fulfillment of the tests required for this study. These are listed as 1) cone penetrometer, 2) Hvorslev trafficability sampler, and 3) spatula stickiness indicator. Discussions of each is presented in the following paragraphs.

Cone penetrometer. This instrument was designed to make rapid readings in soft soils to a depth of 3 feet. The readings are an index of the shearing resistance of the soil, and they are being correlated impirically with the ability of the soil to pass military vehicles.

Figure 63 shows details of the instrument. The stainless steel cone has an apex angle of 30 degrees and a height of 2.106 inches which gives a projected area of 1 square inch. The shaft is steel tubing scored at intervals for use in determining depth. The load-measuring device consists of a proving ring and a 1/1000-inch extensometer. The proving ring is high-

BUREAU OF RECLAMATION
EARTH DAM MATERIALS TESTING

SPECIMEN PLACEMENT DATA SHEET

Sheet ___ of ___

Sample No. 7N-179 Feature Kirwin Dam
Specimen No. 5 Date Feb. 5, 1946
Container No. 4 Compaction ________ Blows

		Initial	Final
(1) Wt. Spec. & Cont. - Air	(gm.)	2352.9	2311.2
(2) Wt. of Container - Air - Rubber Endplate 80.1 / 150[illegible]	(gm.)	1587.7	1587.5
(3) Wet Wt. of Specimen = (1) - (2)	(gm.)	765.2	727.7
(4) Dry Wt. of Specimen = (3) / (1 + $\frac{(12)}{100}$)	(gm.)	583.7	583.7
(5) Wt. of Water = (3) - (4)	(gm.)	181.5	140.0
(6) Wt. Spec. & Cont. - H_2O	(gm.)	1742.4	1740.9
(7) Wt. Loss Spec. & Cont. = (1) - (6)	(gm.)	610.5	570.3
(8) Wt. Loss of Container	(gm.)	210.5	210.8
(9) Wt. Loss of Specimen = (7) - (8)	(gm.)	400.0	359.5
(10) Specimen Volume = (9) / 16,350	(cu. in.)	24.465	21.988
(11) Dry Density = $\frac{(4) \times 62.29}{(9)}$	(lbs./cu. ft.)	90.90	101.14
(12) Moisture, Percent Dry Wt.	(%)	31.09	23.98
(13) Absolute Soil Density = Sp.G. x 62.43	(pcf)	167.94	
(14) Soil Volume = (11) x 100 / (13)	(%)	54.13	60.22
(15) Water Volume = (11) x (12) / 62.29	(%)	45.37	38.93
(16) Free Air Volume = 100 - (14) - (15)	(%)	0.50	0.85
(17) Void Ratio = $\frac{100}{(14)} - 1$		0.847	0.6605
(18) Degree of Saturation = $\frac{(15) \times 100}{100 - (14)}$	(%)	98.91	97.86
		Weighed	Measured
(19) Volume Change	(cu. in.)	-2.48	-2.49
(20) Drainage	(cu. in.)		

Prepared by K.C. Computed by K.C. Checked by R.C.C.

ED-76-44

BUREAU OF RECLAMATION
EARTH DAM MATERIALS TESTING

PORE PRESSURE COMPUTATION SHEET

Sheet ___ of ___

Sample No. 7N-179 Feature Kirwin Dam
Specimen No. 5 Date Feb. 5, 1946

Elapsed Time	Tube Change	Corr.	Volume Change	Volume Change	Water Drainage Top	Water Drainage Bott.	Water Drainage Total	Water Drainage Total	Lateral Press.	Pore Press.	
Hours	Cubic inches			%	Cubic inches			%	p.s.i.	%	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	
:00	0	0		0					12.6	12.6	Consolidation without Drainage
:10	-0.34	+0.27	-0.07	0.29					112.2	111.1	
:20	-0.36	+0.27	-0.09	0.37					"	111.3	
:40	-0.36	+0.27	-0.09	0.37					"	111.5	
1:20	-0.36	+0.27	-0.09	0.37					"	111.7	
3:20	-0.37	+0.27	-0.10	0.41					"	112.0	
6:40	-0.37	+0.27	-0.10	0.41					"	112.1	
13:20	-0.37	+0.27	-0.10	0.41					"	112.1	
33:20	-0.37	+0.27	-0.10	0.41					"	112.1	
1:06:40	-0.37	+0.26	-0.11	0.45					"	112.1	
2:13:20	-0.37	+0.26	-0.11	0.45					"	112.1	
2:46:40	-0.37	+0.26	-0.11	0.45					"	112.1	
5:33:20	-0.36	+0.25	-0.11	0.45					"	112.1	
24:00:00	-0.37	+0.25	-0.12	0.49					"	112.1	
:10	-0.64	+0.26	-0.38	1.55		0.27	0.27	1.10	"	112.1	With Drainage
:20	-0.74	+0.26	-0.48	1.96		0.43	0.43	1.76	"	112.1	
:40	-0.88	+0.26	-0.62	2.53		0.53	0.53	2.17	"	112.0	
1:20	-1.05	+0.26	-0.79	3.23		0.72	0.72	2.94	"	112.0	
3:20	-1.47	+0.26	-1.21	4.95		1.12	1.12	4.58	"	111.9	
6:40	-1.83	+0.26	-1.57	6.42		1.48	1.48	6.05	"	103.5	
13:20	-2.29	+0.26	-2.03	8.30		1.94	1.94	7.93	"	65.3	
33:20	-2.66	+0.26	-2.40	9.81		2.30	2.30	9.40	"	22.4	
1:06:40	-2.76	+0.25	-2.51	10.26		2.41	2.41	9.85	"	14.6	
2:13:40	-2.82	+0.25	-2.57	10.50		2.47	2.47	10.10	"	12.8	
2:46:40	-2.85	+0.25	-2.60	10.63		2.50	2.50	10.22	"	12.4	
5:33:20	-2.87	+0.25	-2.62	10.71		2.52	2.52	10.30	"	12.3	
24:00:00	-2.96	+0.27	-2.69	11.00		2.59	2.59	10.59	"	12.2	
	-2.96	+0.27	-2.69	11.00					"		Percolation
	-2.95	+0.26	-2.69	11.00					"		
	-2.95	+0.26	-2.69	11.00					"		
	-2.99	+0.28	-2.71	11.08					"		
	-2.97	+0.26	-2.71	11.08					"		
	-2.54	-0.01	-2.55	10.42					12.5		Expansion
	-2.48	-0.01	-2.49	10.18					12.5		

Form No. E.D.-63-46 Computer K C Checker ______

BUREAU OF RECLAMATION
EARTH DAM MATERIALS TESTING

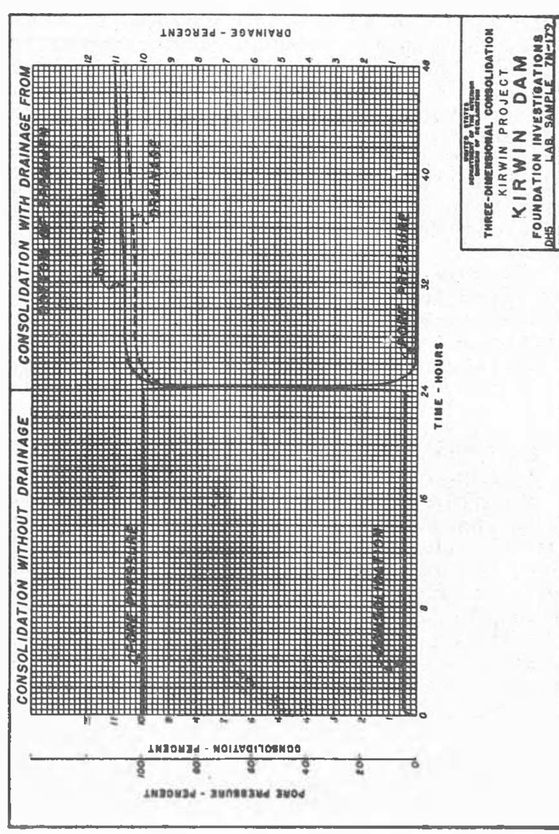
PORE PRESSURE TEST DATA SHEET

Sheet ___ of ___

Sample No. 7N-179 Cylinder No. 2 Feature Kirwin Dam
Specimen No. 5 Recorder K C Date Feb 5, 1946

Date	Time Actual	Top Press.	Bottom Press.	Lateral Press.	Volume Tube	Drain. Tube	Air Tube	Water Temp.	Barometer	
		psi absolute			Inches			Deg F.	psi	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
2-5-46	:00	12.6		12.6	1.00			70.8	12.16	Consolidation with no drainage
	:10	111.1		112.2	2.01			"	"	
	:20	111.3		"	2.04			"	"	
	:40	111.5		"	2.04			"	"	
	1:20	111.7		"	2.06			"	"	
	3:20	112.0		"	2.07			"	"	
	6:40	112.1		"	2.07			"	"	
	13:20	112.1		"	2.08			"	"	
	33:20	112.1		"	2.08			70.9	"	
	1:06:40	112.1		"	2.08			71.0	"	
	2:13:20	112.1		"	2.08			"	"	
	2:46:40	112.1		"	2.08			"	"	
	5:33:20	112.1		"	2.06			71.3	"	
2-6-46	24:00:00	112.1		"	2.07	1.00		"	12.20	
	:10	112.0		"	2.85	1.74		"	"	Consolidation with free drainage one end
	:20	112.0		"	3.14	2.17		"	"	
	:40	111.9		"	3.55	2.44		"	"	
	1:20	111.9		"	4.14	2.95		"	"	
	3:20	111.8		"	5.25	4.03		"	"	
	6:40	103.4		"	6.28	5.00		"	"	
	13:20	65.2		"	7.61	6.27		"	"	
	33:20	22.3		"	8.65	7.26		"	"	
	1:06:40	14.5		"	8.95	7.54		71.4	"	
	2:13:20	12.7		"	9.11	7.71		71.5	"	
	2:46:20	12.3		"	9.20	7.80		"	"	
	5:33:20	12.2		"	9.25	7.86		71.6	"	
2-7-46	24:00:00	12.1		"	9.50	8.03		71.1	12.10	
	10:00			"	9.50	30.64	37.2	71.1	"	Percolation
2-8-46	2:00	7.5		"	9.48	9.56	37.2	71.3	12.20	
	2:30			"	9.48	30.00	37.2	"	"	
2-9-46	8:00	2.58		"	9.59	22.62	37.2	70.5	12.25	
	3:00	0.86		"	9.54	20.24	37.2	71.2	"	
	3:01			12.5	8.31			71.2	"	Expansion
	4:00			12.5	8.13			71.3	"	

Form No. ED-52-41 Tube A refilled to initial volume of 30.0



Three-dimensional Consolidation - Data and Curve Sheets

FIG. 67

carbon steel, heat treated after construction. The dimensions of the proving ring were selected to give a deflection of about 0.1 inch under a 200-pound load. The original face of the extensometer has been replaced with a face calibrated to read load in pounds directly. A spherical handle is used to eliminate eccentric loading as far as possible. Figure 64 is a view of this instrument. In use, the cone is forced into the soil to the desired depth. The load is then released slightly and reapplied slowly. The load required to just start the cone moving is taken as the cone index.

Hvorslev trafficability sampler. This sampler was developed for rapid sampling of relatively soft deposits to a depth of 3 feet for use in determination of moisture and density. A unique feature of the sampler is that a known volume of soil is obtained during ejection of the sample. Figure 65 is a view of the sampler.

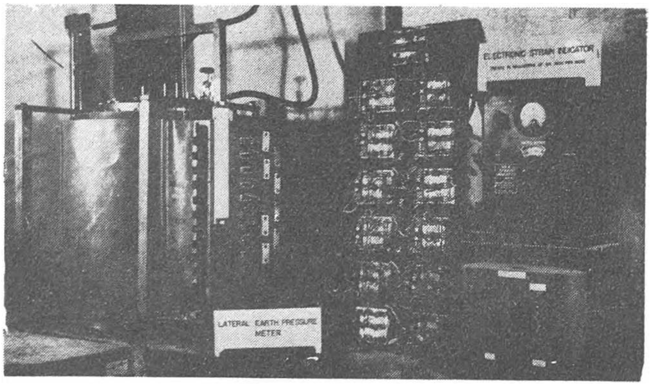
The sampler consists of a thin-walled stainless steel tube 9-1/4 inches long by 1.87 inches inside diameter with a wall thickness of 0.035 inch. The outside of the cutting edge is beveled, and the inside diameter of the cutting edge is made smaller to give a relief of approximately 0.75 percent of the diameter. The tube is fitted with an internal head so that successive samples can be taken in the same boring. A hollow shaft with T-handles at the top is attached to the head. A piston is provided in the sample tube which is operated by a rod inside the hollow shaft. A combination handle and baseplate is attached to the piston rod. Two spacer bars are provided for use in trimming the sample to a predetermined length as it is ejected from the tube.

In use, the sampler is forced into the soil, holding up slightly on the piston rod handle. When the sampler is full, the piston rod is locked in place by turning the knurled handle, and the sampler is rotated to break the sample. The sample tube is then removed from the soil, inverted, and a sample exactly 4 inches long is cut off and used for moisture and density determinations. The sampler has proved satisfactory over a wide range of soil types, all of which have been in a relatively soft condition. The sampler has since been constructed in a 3-inch diameter size and extended so that it can recover samples at depths up to 6 feet.

Spatula stickiness indicator. The spatula stickiness indicator is a slight modification of the Atterberg "sticky" limit test described by Atterberg in Plasticity of Clays. The original "sticky" limit is defined as the minimum moisture content at which the soil will stick to a nickel spatula. As modified for trafficability purposes, a stainless steel spatula is used, and adherence to the spatula is divided into three degrees: none, some, and complete. The test is conducted by drawing the face of the spatula across the surface of the soil to be tested and noting the adherence of the soil to the spatula. The degrees of adherence are being correlated with the capacity of soils to adhere to vehicles. General indications are that when the soil shows "complete" in the spatula test, it is wet enough to adhere to vehicles.

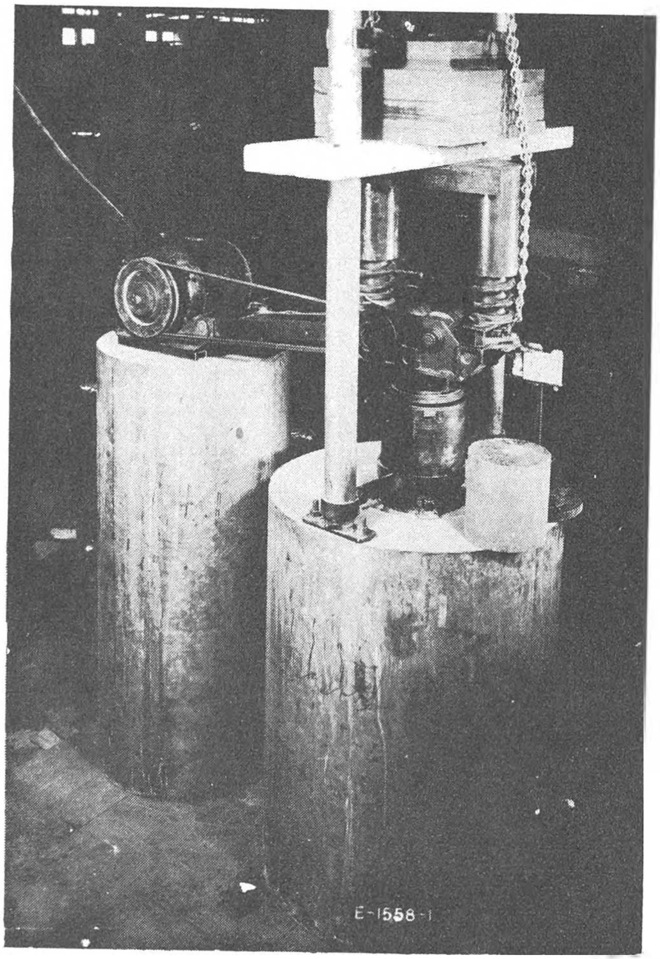
9. Combined Pore Pressure-Percolation-Consolidation Test

General. This combined test, as used by the Bureau of Reclamation, is intended to furnish data for the study of pore pressure and the influence of the related factors of percolation and consolidation. The data obtained furnish information for 1) estimating the pore pressure that may be produced in an earth structure during construction, 2) estimating the rate of pore pressure dissipation in an earth structure, and 3) estimating the seepage loss through an earth structure. The basic theory of this test is very similar to the consolidation test, except that emphasis is placed on the compressibility of the pore fluid and the resulting pore pressure.



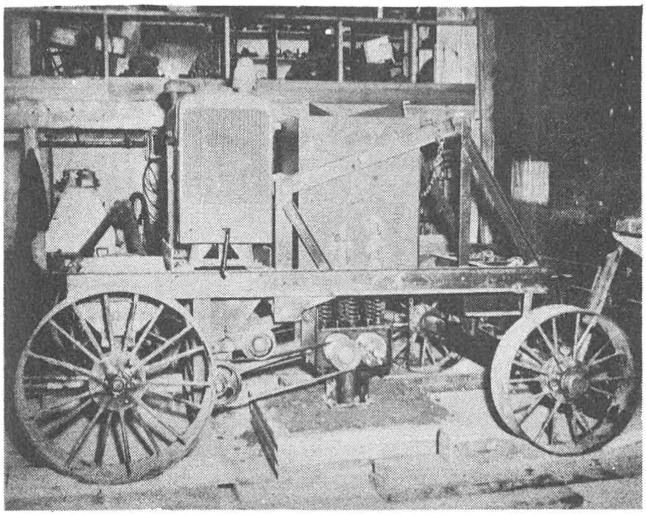
Lateral Earth Pressure Meter

FIG. 68



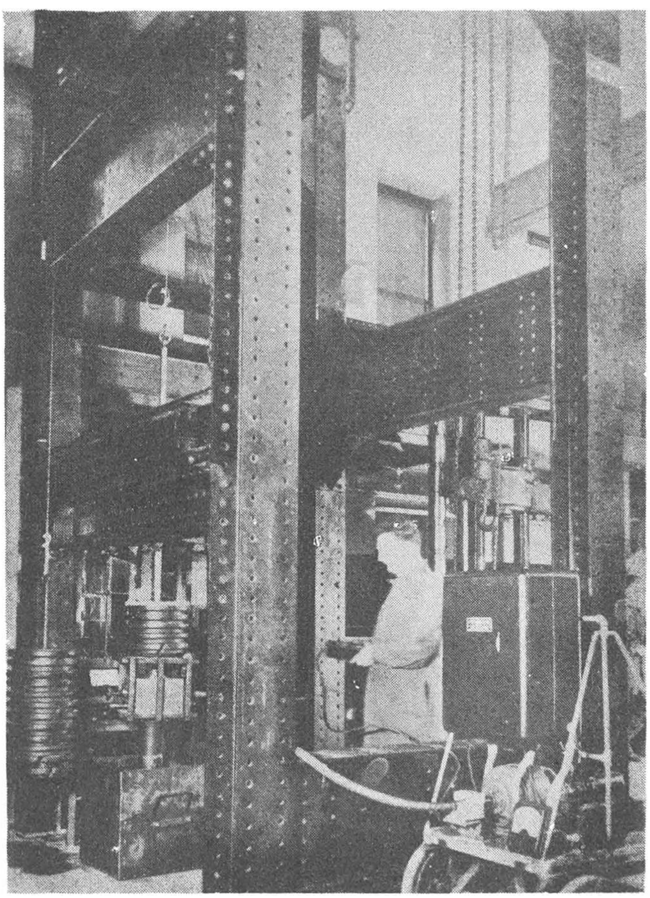
Vibratory - Impact Machine - Laboratory Model

FIG. 69



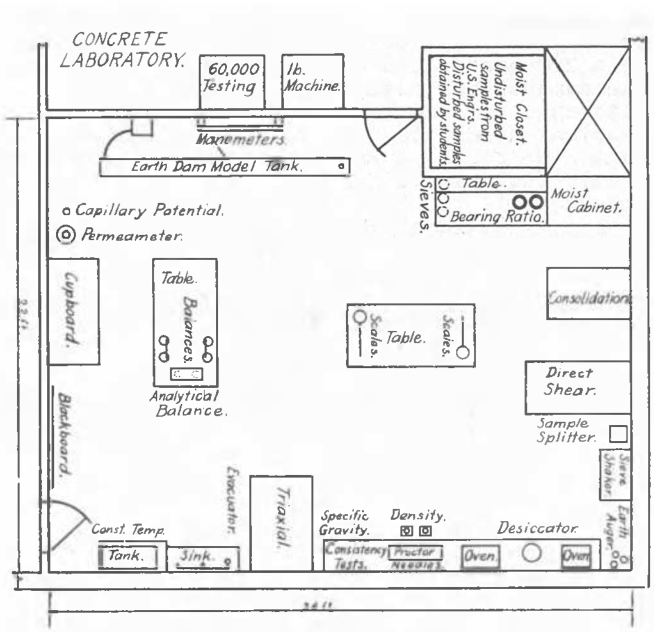
Vibratory - Impact Machine - Field Model

FIG. 70



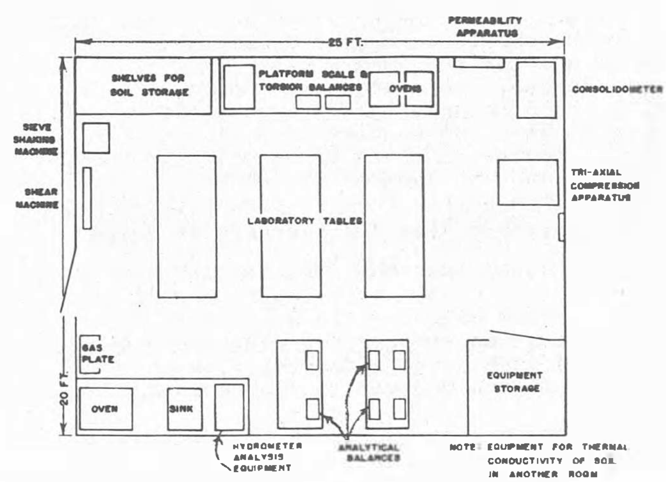
Vibratory Machine - Laboratory Model

FIG. 71



Laboratory Plan Clarkson College of Technology

FIG.72



Laboratory Plan University of Minnesota

FIG. 73

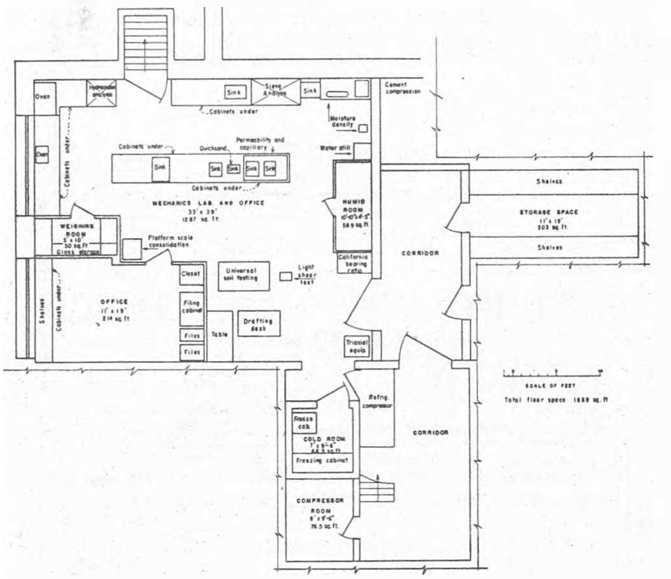
Testing equipment. The combined pore pressure-percolation-consolidation test apparatus is essentially as follows: 1) a cylindrical soil specimen is encased in a thin-wall rubber sleeve, and has perforated plates at each end that are connected to tubes which may be opened or closed to control drainage from the specimen as test conditions may warrant; 2) the perforated end plates are also connected to no-flow pressure cells for pore pressure measurements; 3) the rubber-encased specimen is placed in a pressure chamber which contains water surrounding the sealed specimen; 4) the loading on the specimen is obtained by applying a controlled air pressure to the water in the pressure chamber; and 5) a calibrated glass gage is located between the pressure cylinder and the air control tank. The volume of water flowing to or from the pressure chamber is measured on the gage as differences in water level; these differences, when corrected and converted into volume, give a measure of the volume change of the specimen.

Test procedure. The test procedure is essentially as follows: 1) Measure carefully the initial weight and volume of the specimen. 2) Place it in the apparatus and make necessary connections to drainage lines and pressure measuring lines. 3) Load the specimen and observe the development of pore pressure and the amount of consolidation with the drainage line closed. 4) After the consolidation and pore pressure development cease, one end of the specimen is opened to drainage. 5) The pore pressure measurements are continued on the opposite end at frequent and measured time intervals during drainage, and the amount of additional consolidation is observed and recorded. 6) After the pore pressures have dissipated and the consolidation has ceased, the remaining drainage line (connected to the top perforated plate) is opened and water is forced to percolate through the specimen until the percolation rate becomes constant. 7) After the percolation test is completed, a definite hydrostatic pressure is built up at one end of the specimen, a valve in the pressure line is closed, and the drop in this percolation pressure is observed at frequent and measured time intervals. If the permeability rate is desired for higher load conditions, increase the load on the specimen as desired and repeat the permeability process outlined above.

Two sizes of specimens are used in the Denver laboratory for this test; one size is 3-1/4 inches in diameter by 3 inches long and the other is 3-1/4 inches in diameter by 9 inches long. The shorter length is used for soils of very low permeability, and the longer length is used for soils of moderate or high permeability. These specimens may be of compacted soil or may be cut from undisturbed samples. The equipment used for this test is shown by Figure 66. Figure 67 shows the data and plot sheets used for computing and presenting the test data.

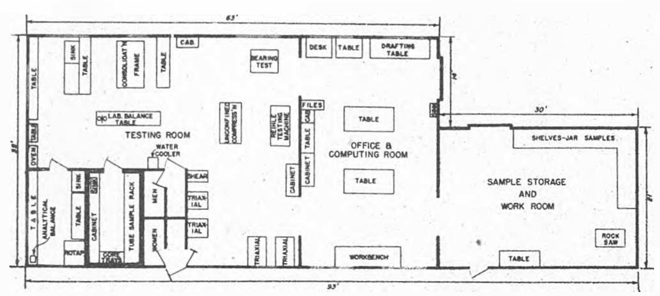
10. Lateral Pressure Meter

A device for determining lateral pressures of cohesive and noncohesive soils under high (up to 3 tons per square foot) vertical pressures has been developed at Princeton University. This consists of a massive steel half-cylinder 12 inches in diameter and 18 inches



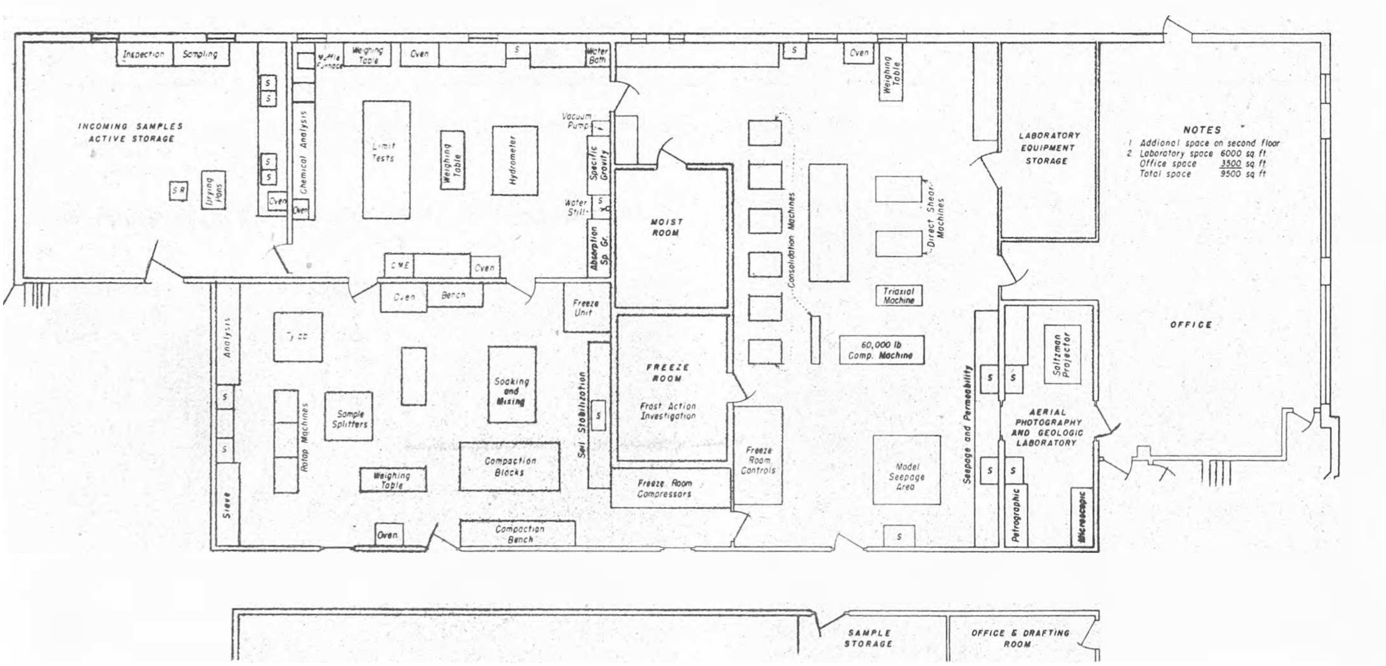
Laboratory Plan - University of Maine

FIG. 74



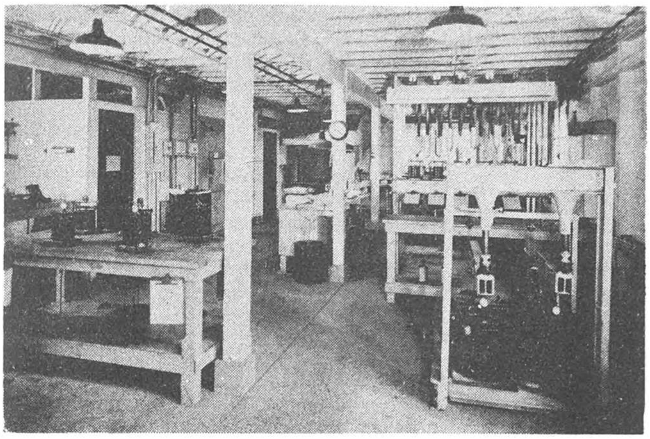
Laboratory Plan - Panama Canal

FIG.76



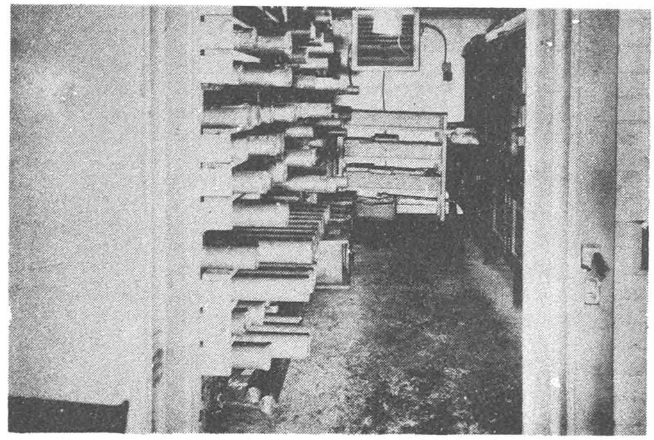
Laboratory Plan - Department of Public Works, New York

FIG. 75



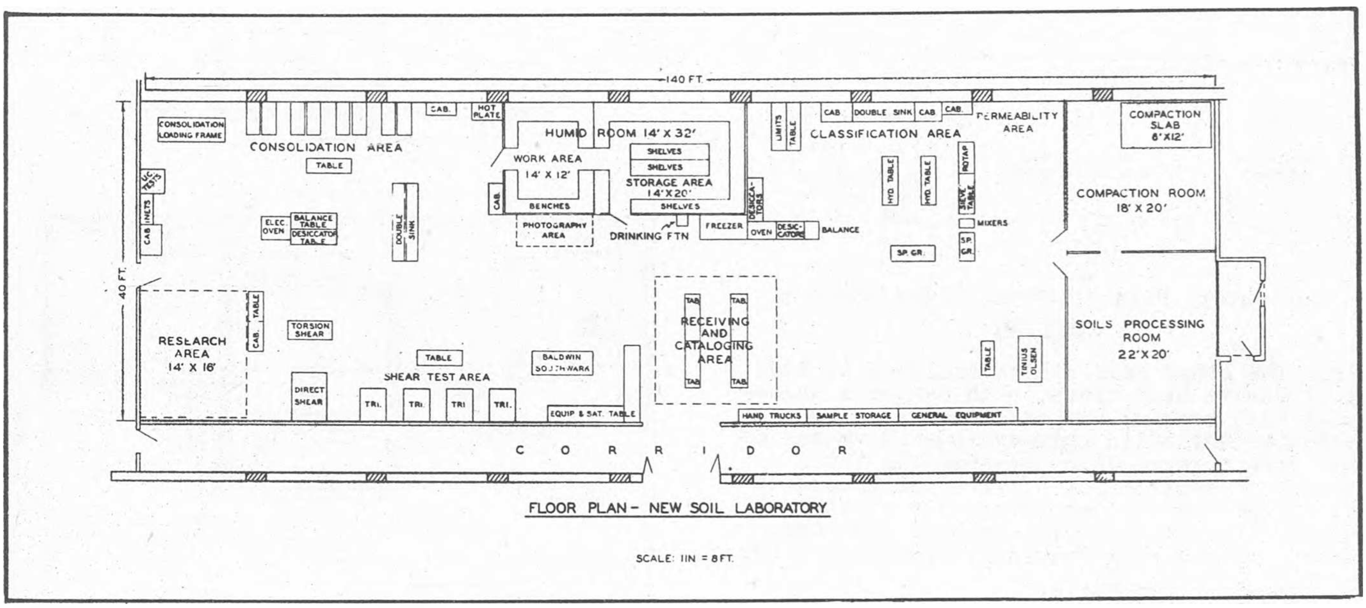
Testing Room - Panama Canal

FIG. 77



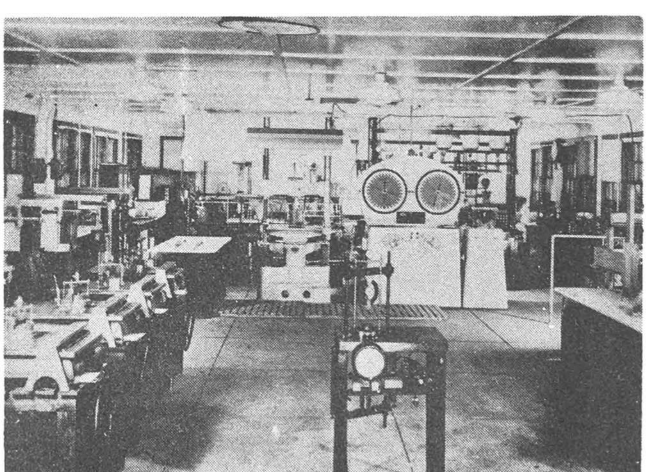
Humidity Room - Panama Canal

FIG. 78



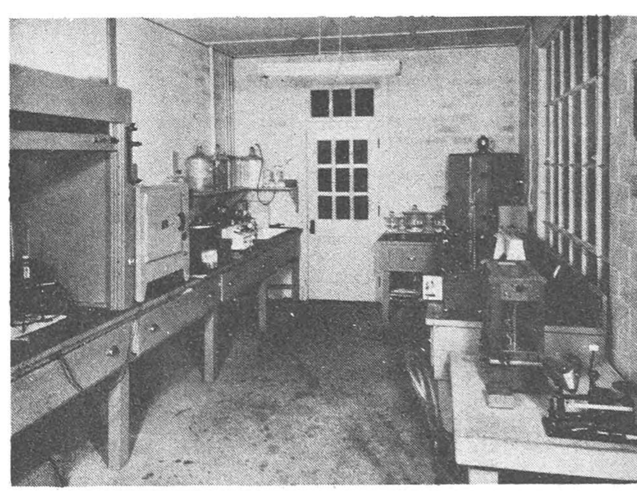
Laboratory Plan - Waterways Experiment Station

FIG. 79



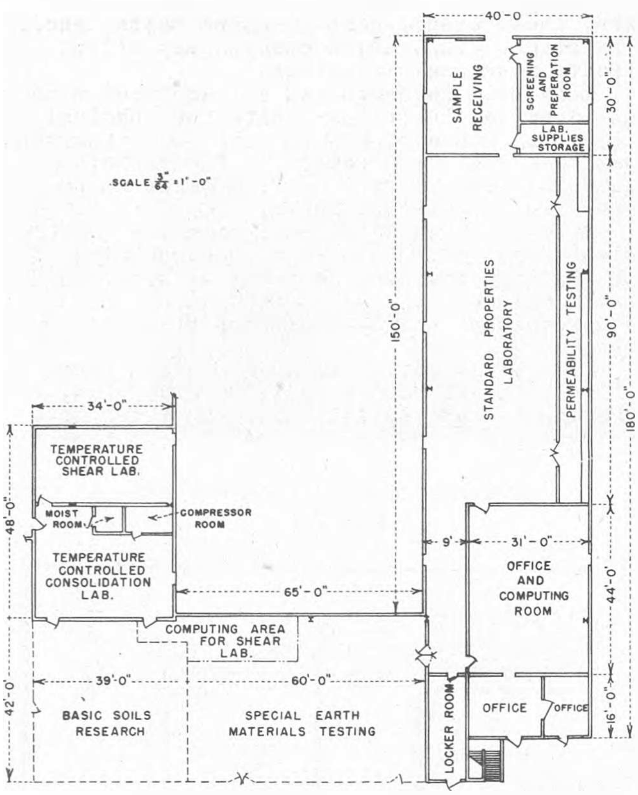
Testing Room Waterways Experiment Station

FIG. 80



Soil Chemistry Laboratory - Waterways Experiment Station

FIG. 81



Laboratory Plan - Bureau of Reclamation

FIG. 82

high. The other half of the cylinder is made up of twelve half-rings, each having a three-point ball bearing support. Each ring is connected to the solid half-cylinder by means of SR-4 strain gages which measure the total lateral pressure exerted. Vertical pressures are transmitted by compressed air to the soil surface through a flexible rubber membrane. Lateral drainage is provided. (See Figure 68)

11. Vibratory Compaction

The Bureau of Reclamation is conducting a research investigation on the compaction of soils by vibratory-impact methods. The compaction apparatus is a two-mass system consisting of a vibrating head and a static load separated by springs. The vibrating head is actuated by oppositely revolving eccentric weights. Figure 69 shows the laboratory model and Figure 70 the field model used for conducting these experiments. This apparatus was developed by the Barber-Greene Equipment Company. A detailed program to investigate the effect of vibration on soils has been carried out at Princeton University. This work and the equipment are described in detail in a paper entitled Effect of Vibration on the Bearing Properties of Soils by Gregory Tschebotarioff, Proceedings of the Highway Research Board, 1944. Figure 71 shows the vibration testing equipment used for this program.

L. LABORATORIES AND GENERAL FACILITIES

Information contained in the questionnaire indicated that the aerth materials laboratories varied in size, facilities, and arrangements according to their purposes. The size, personnel, purpose, and general facilities for the various laboratories are noted in Table 1. Many of the larger agencies interested in con-

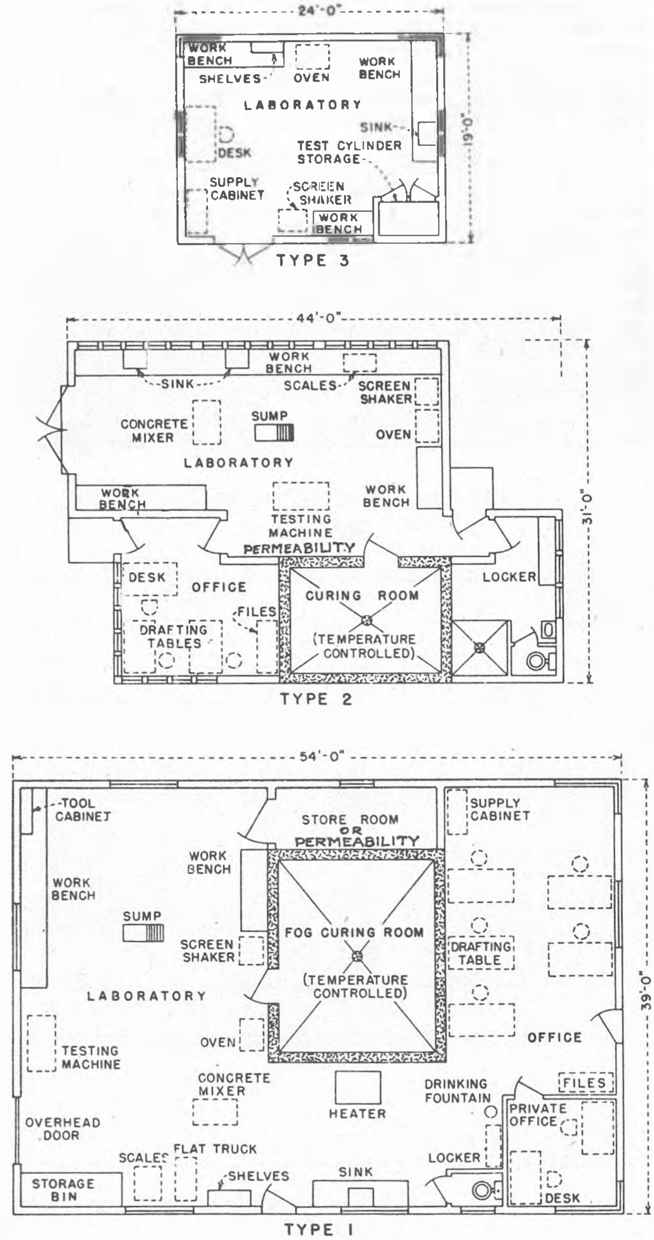


FIGURE 1 - FIELD LABORATORY FACILITIES COMMENSURATE WITH THE REQUIREMENTS OF THE WORK SHOULD BE PROVIDED

Field Laboratory - Bureau of Reclamation

FIG. 83

struction maintain a large central laboratory for complex testing for research work and design purposes, and numerous district or project field laboratories for construction control or investigation purposes. For instance, the Corps of Engineers (War Department) maintains two large, well equipped laboratories having facilities and personnel to conduct all types of soil tests. These are the Waterways Experiment Station at Vicksburg, Mississippi, and the Ohio Division Laboratories at Cincinnati, Ohio. In addition, field laboratories are maintained at Division and District Offices for the purpose of design, construction control, and investigation, and small laboratories are established on each major project for control during construction. The Bureau of Reclamation (Department of the Interior) maintains a large well equipped central laboratory at Denver, Colorado, for research work and design purposes. Small laboratories are established on each major project for control during construction. Some region and district laboratories are being established to assist in investigation programs.

In addition to the testing equipment which was discussed in previous paragraphs, many laboratories have special facilities which are an aid to their work. Special moist rooms for the storage and preparation of undisturbed samples are advantageous where a considerable amount of foundation testing and research work is being done. These moist rooms help to maintain the initial moisture content of samples in storage and prevent the drying out of soil specimens during preparation.

In many instances temperature controlled rooms are advantageous for maintaining constant temperature condition with consolidation tests, shear tests, pore pressure tests, etc., where slight temperature changes may affect delicate instrument readings.

Many soil laboratories are equipped with small chemical laboratory units for chemical analysis in connection with soil test programs. Freezing units are provided in laboratories conducting freezing and thawing tests on untreated and stabilized soils.

Special investigations frequently require various types of models in connection with soil testing programs. They may be models of dams, models of backfilled structures, models for determining the dynamic properties of soils, etc.

Several laboratories of all sizes have been selected at random to illustrate size, arrangement, and facilities. These illustrations are given on the figures 72 - 83.

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