17. Loos, "Modellversuche mit Mooreinlagerungen in Sand", Der Strassenbau 1935, Nr. 5.
18. Loos, "Erkenntnisse der neueren Baugrund-forschung bei der Gründung von Bauten", Zentralblatt der Bauverwaltung 1935, H. 12.
19. Loos, "Anwendung der neueren Baugrundforschung bei der Beurteilung von Erdbauten und Gründungen", Die Bautechnik 1935, H. 15.
20. Loos, "Verdichtung geschütteter Dämme", 2. Bericht, Die Strasse 1935, H. 13.
21. Loos, "Bericht über die Moorversuchsstrecke bei Bremen", Die Strasse 1935, H. 16.
22. Loos, "Risse in Bauten auf nachgiebigem Untergrund", Bauwelt 1935, H. 38.
23. Hertwig und Lorenz, "Das dynamische Bodenuntersuchungsverfahren", Der Bauingenieur 1935, H. 25/26.
24. "Schwingungsuntersuchungen an Betonstrecken der Autobahnen München und Frankfurt/Main", Die Strasse 1935, H. 10.
25. A. Ramspeck, "Dynamische Bodenuntersuchungen an der Reichsautobahn Stuttgart-Ulm", Die Strasse 1935, H. 18.
26. R. Müller und A. Ramspeck, "Verdichtung geschütteter Dämme, 3. Bericht, Die Strasse 1935, H. 18.
27. Loos, "Praktische Anwendung der Baugrunduntersuchungen bei Entwurf und Beurteilung von Erdbauten und Gründungen", Verlag von Julius Springer, 1935.
28. Loos, "Der Nutzen geeigneter Baugrunduntersuchungen für den Bauunternehmer", Die Bauindustrie, Berlin, III. Jg., Nr. 49 vom 7. 12. 1935.
29. A. Ramspeck, "Dynamische Untersuchung von Strassendecken", Die Betonstrasse 1936, Nr. 2.
30. Loos, "Behandlung von Bodenproben bei Baugrunduntersuchungen", Heft 3 der Schriftenreihe der "Strasse" 1936.

9. Observations on structures are in progress. However, in most cases they have not extended over a sufficiently long period to permit conclusions. Only in some cases was it possible to determine whether settlement predictions are correct. Thus, e.g., tanks in northern Germany have settled in the first year 36 cm, as compared with a total predicted settlement of 70--90 cm which will probably be reached in the course of time. In many cases the predicted settlements are 50 to 100% higher than the actual settlements.

No. A-23 THE SOIL MECHANICS LABORATORY OF THE U. S. WATERWAYS EXPERIMENT STATION VICKSBURG, MISSISSIPPI

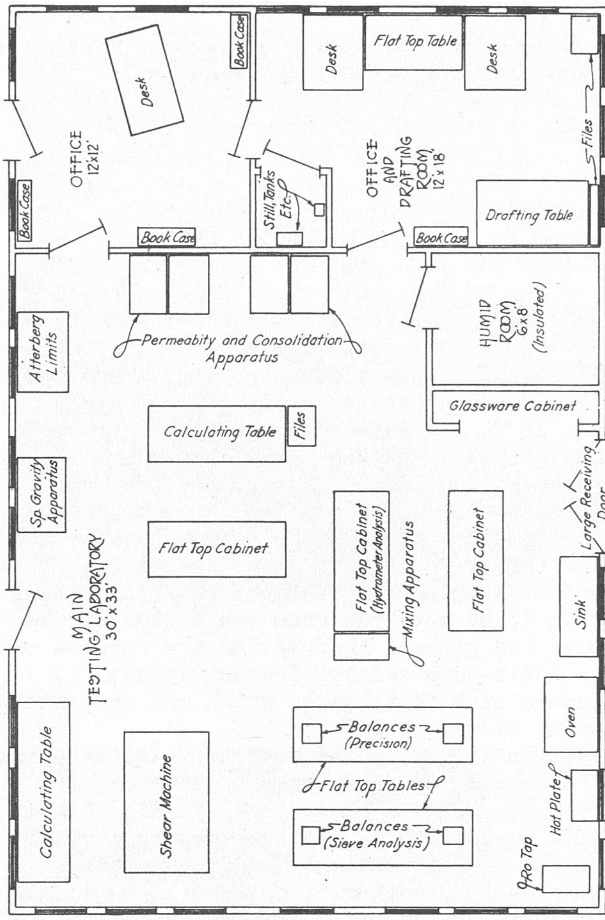
Spencer J. Buchanan, Associate Engineer

Introduction. In the summer of 1933 the activities of the U. S. Waterways Experiment Station, an office of the U. S. Engineers, located at Vicksburg, Mississippi, were broadened to include studies in the field of soil mechanics. Knowledge in this field is especially applicable to the controlling of floods in waterways or streams by means of earthen structures, such as levees and dams. The charge of this activity was vested in the author who is assisted in the execution of the work by a staff of ten men of the professional and sub-professional grade.

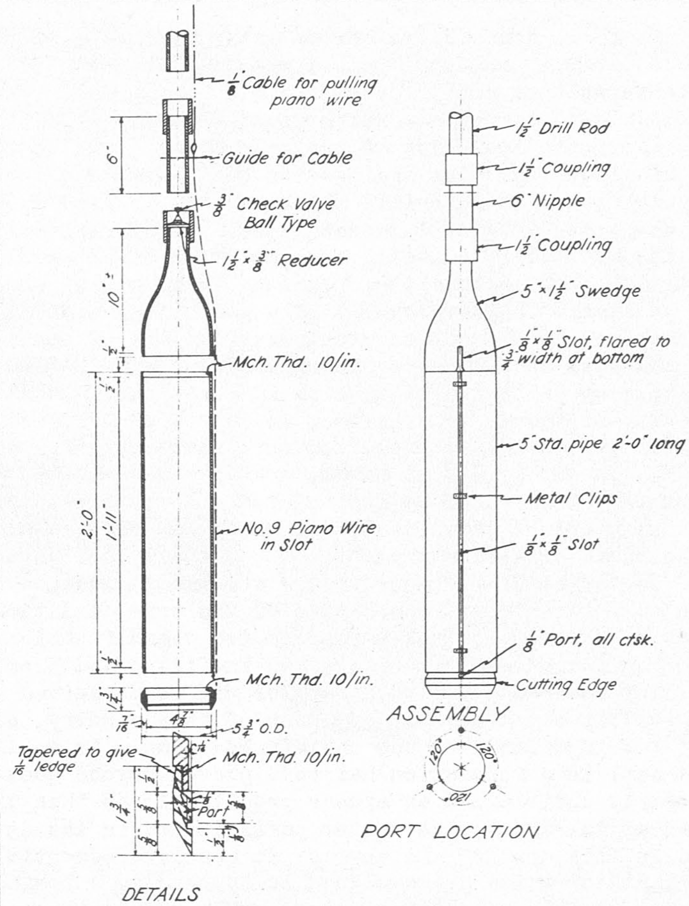
It is the purpose of this paper to summarize the prominent phases of the work of the Laboratory which serves the U. S. Engineer Department, particularly its Offices that are not equipped to make investigations of the soil problems developing on projects under their supervision. The other sections of the Station are also served in so far as the physical properties of soils and sediment are concerned in their studies of hydraulic models. The work consists essentially in the application of the results of research already developed in this field to the problems submitted, rather than in pure research or instruction; however some research is done when desirable. The methods of testing described in this paper are subject to change as improvements in them are developed.

Plant. The Laboratory is maintained as a separate unit of the Station and its organization housed in an independent building which, in addition to the testing laboratory and office space, has ample storage facilities for all types of soil and sediment samples and the special equipment for their procurement. A general view of the Laboratory is shown by Fig. 1 and a diagrammatic sketch of the plant by Fig. 2. The design of the building was arranged to provide for the admittance of a maximum amount of natural light to all of its parts. The apparatus used will not be discussed at this point but later under another heading.

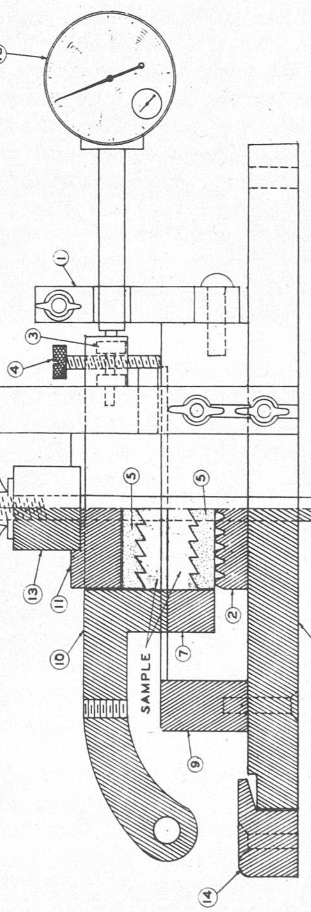
General Nature of Problems. The problems assigned may be divided into two classes: first, those pertaining to the engineering use of soils for structures and foundations; and second, the study of bed materials for models of rivers and tidal basins, and for their prototypes. The latter class will not be discussed in this paper. The solution of a problem is divided into three phases: first, exploration and sampling of the soil involved, field supervision for which may be furnished by the Laboratory; second, the determination of the physical properties and strength of the material; and third, the interpretation of the test results, development or investigation of the design, and report on the problem. The third phase will not be discussed in this paper for space and time do not permit.



FLOOR PLAN AND
ARRANGEMENT OF EQUIPMENT
FIGURE 2



SAMPLING TUBE
FIGURE 7

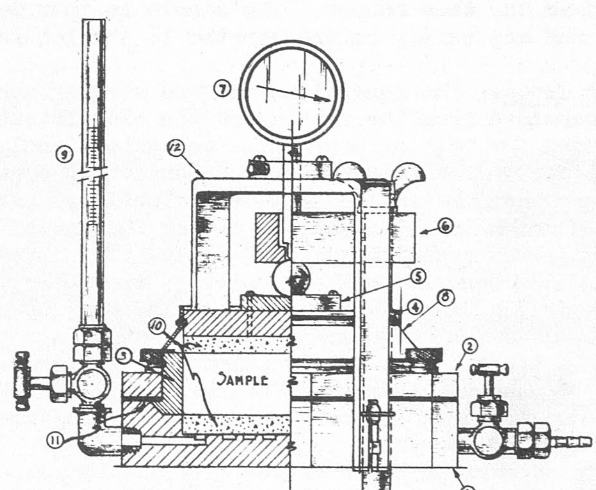


LEGEND
1 GAGE BRACKET
2 FILLER PLATE
3 ADJUSTABLE SCREW & LOCK NUT
4 LIFT SCREW
5 POROUS STONES
6 ORIENTING PINS
7 FILLER BLOCKS
8 BED PLATE
9 LOWER FRAME OF FRICTION BOX
10 UPPER " " "
11 SHEAR FRAME PISTON
12 GAGE BRACKET SUPPORT
13 WEIGHT HANGER YOKE
14 BED PLATE STOP
15 EXTENSOMETER

SHEAR BOX
FIGURE 13

LEGEND

1. BASE.	7. EXTENSOMETER.
2. LOCKING RING.	8. RUBBER MEMBRANE.
3. CYLINDER.	9. GRADUATED STANDPIPE.
4. CAP.	10. POROUS STONES.
5. BEARING PLATE.	11. RUBBER GASKET.
6. LOADING YOKE.	12. GAGE BRACKET



CONSOLIDATION APPARATUS
FIGURE 15

Exploration. A knowledge of the materials to be dealt with must first be gained so that their arrangement in strata, and the kind, state, and strength of each may be determined. This is accomplished by exploring the materials by shafts, in the form of test pits or borings, and sampling them as they are exposed. The latter operation requires every precaution and care for the removal of the undisturbed samples if the condition of the material in situ is to be authentically determined by test. Open excavations or test pits are used to best advantage for shallow explorations of cohesionless soils or very dry cohesive materials which can not be readily penetrated by drilling tools not requiring water for their operation. A recent paper (1) (Numbers refer to the Bibliography at end of the paper) by Dr. Glennon Gilboy contains a description of an excellent method for obtaining any kind of samples by this method of exploration. Various means may be used for making borings, the type depending upon the problem: the development of a geological profile may well be accomplished by means of some type of wash boring from which continuous samples of considerable length will serve satisfactorily; but, for the detailed study requiring undisturbed specimen it is essential that the use of any water in the drilling operation be eliminated if practicable. Satisfactory borings can generally be made with augers, six inches in diameter, to depths of 200 feet; this size is sufficient to permit the removal of any type of samples required for laboratory analysis. Depths not to exceed 60 to 70 feet may readily be explored with hand operated equipment of the type shown in Fig. 3, that is provided no sizeable gravel is to be encountered. It is necessary to use a power driven machine for penetrating depths in excess of 70 feet; one which has proven satisfactory and operates on the same principle as the hand auger is shown in Fig. 4. The distinct advantage of this type of equipment is that its operation causes no disturbance of the stratum in advance of the actual cutting operation, thus permitting samples which are representative of the true condition in situ to be obtained from the bottom of the shaft. The representative samples for classification purposes and general information are removed directly from the auger bits shown in Fig. 3 and 5 or with a split-tube sampler frequently used by drilling contractors. Such samples may be preserved in standard pint fruit jars, which are inexpensive and readily obtainable in any part of this country, or in small canvas sacks.

The importance of the undisturbed sample in an investigation involving the condition and strength of a soil in a foundation has been proved beyond question. A device for securing such samples, or as nearly undisturbed as appear practicable at this time, of silts and clays, is shown in Fig. 6 and detailed in Fig. 7; the writer participated in its development during 1931. The tube has been widely used in this country and abroad; it consists essentially of a barrel, convenient head, and cutting shoe, all of which are designed to operate in a boring six inches in diameter. The shoe is arranged to cut a sample slightly smaller in diameter than the retaining barrel, thus minimizing resistance to its entrance. No arching action can develop to distort the sample as the tube is driven into place with a 100-lb hammer. The shoe is recessed for a system of wire snares that spring into place and clear the sample during its entrance but become operative at the desired time, making a complete cut of its bottom face to sever it from the deposit. The operation of the snares is achieved by a connecting cable that extends to the surface; the cable is shown in Fig. 7. A check valve in the head of the tube prevents the forcing out of the sample due to the partial vacuum created by the piston-like action of the tube upon withdrawal from the stratum after the snare wires have done their work. When the above operation have been completed, the tube is raised to the surface, disconnected from the $1\frac{1}{2}$-inch drive pipe, and placed in a convenient horizontal position; the snare wires and check valve removed, and a flexible hose from an air reservoir attached in place of the valve. Pneumatic pressure is slowly developed in the head of the tube until sufficient force is created to push the sample out through the cutting shoe. A brush coat of molten paraffin or a sheet of cellophane is applied to the outer surface of the sample as it is forced free. When the desired length of about ten inches has been forced out, it is cut off with a wire soil-saw; if more remains in the tube, it too is forced free and treated in the same manner. The sample is then sealed with paraffin in a convenient sheet iron container and may safely be transported to the laboratory.

General Tests. The general nature and stratigraphy of the soil in the foundation and borrow-pit areas are determined from the results of the classification tests made on the representative samples. The tests used for this purpose are: mechanical analysis, Atterberg Limit, absolute specific gravity of mineral matter, water content, and content of organic matter. When required, other tests are made, such as: chemical analysis, water solubility, grain shape, and relative density.

The mechanical analysis is a test that is of considerable assistance and one used by most investigators for the classification of soils. The cohesionless or coarse-grained materials are analyzed by means of mechanically agitated sieves; the cohesive or fine-grained materials by the method (2) developed by Dr. Casagrande which uses the density hydrometer. The tests in themselves have become so well standardized as to merit no discussion; however, the manner of showing the results usually differs with each laboratory. The adoption of a uniform standard for this purpose would facilitate the interchange of information without confusion. A quick, simple, and economical method (shown in Fig. 8), making use of stock sheets supplied by any engineering supply house, has been used by the author. Its use for general purposes is strongly advocated.

The comparison of cohesive materials by means of the limit tests made by A. Atterberg (3) and later improved and completely described by Dr. Casagrande (4) has been very satisfactory. The equipment used for one of these limit tests (the liquid limit) is shown in Fig. 9. The results of these tests are valuable as a means of grouping soil samples so that representative specimens may be selected for complete investigation. Also, as has been indicated by Mr. Philippe (5), the plastic limit serves as a guide for determining the optimum content of water for the placement of material in earthen structures. The observations of the writer have verified this indication.

FIGURE 1

FIGURE 6

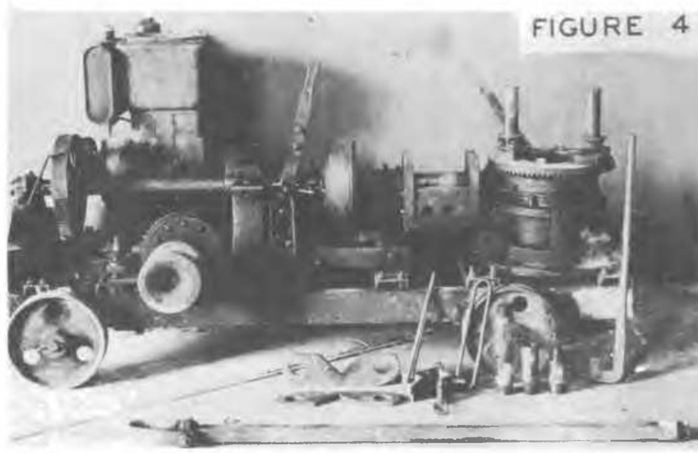


FIGURE 4

FIGURE 5

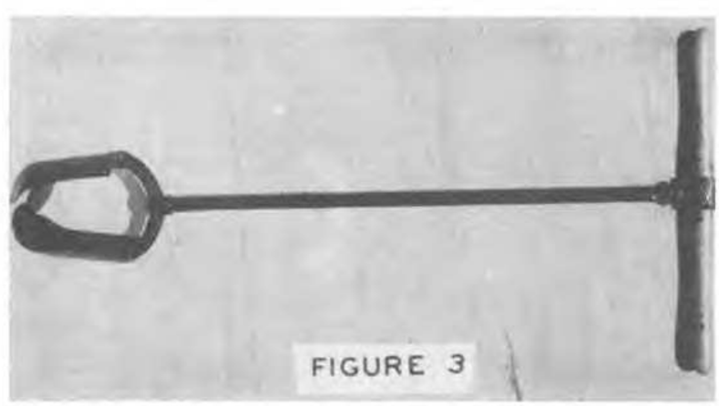


FIGURE 3

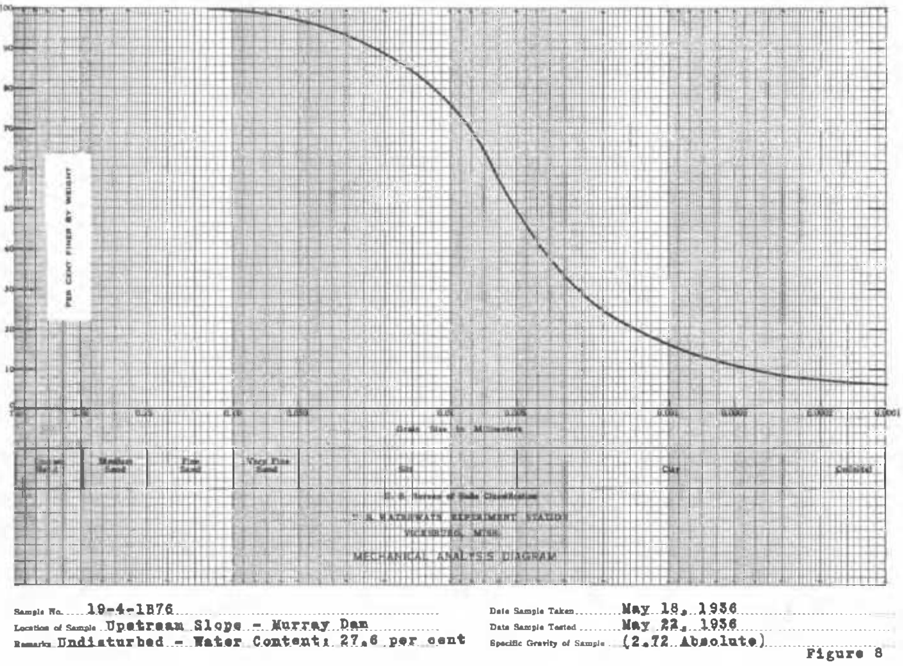


Fig. 8

The absolute specific gravity of the mineral content of a soil is a factor required in numerous soil tests and serves in some instances as a guide for its classification. The method of determining this factor is a modification of a similar test used by the U. S. Department of Agriculture. The procedure and technique is essentially that described elsewhere (6) except that a vaccum is used to extract the void-entrapped air; a reduction in pressure from 760 mm to 10 mm is used. A means is provided for determining the presence of residual air in the specimen and suspension, contained in the pycnometer bottle, at any stage of the test by observing the variation of the level in the neck of the bottle accompanying the reduction and reapplication of atmospheric pressure. The magnitude of this variation is directly proportional to the quantity of residual air remaining in the contents. The ultimate requirement is that no variation in level shall occur, except that due to the expansion and contraction of the pyrex glass bottle. The apparatus used for the performance of the test is shown in Fig. 10.

Major Tests. The condition, strength, and perviousness of soils in situ are determined by the more detailed tests of the undisturbed samples. The information yielded by such tests is necessary in effecting satisfactory designs for earthen structures and the solution of problems in foundation engineering. The principal tests performed are: shear, in both the undisturbed and remoulded condition; consolidation; and permeability.

Shear Tests. The determination of the angle of internal friction and cohesive strength are made by the direct method of testing following either the delayed or quick procedure. The former of these procedures is used in determining the angle of internal friction and shearing-cohesive strengths, data used in the design of earthen slopes; the latter, in determining the ultimate shearing strengths of soils in their natural state of consolidation.

The apparatus consists of a loading machine by which vertical and horizontal stresses may be developed in a specimen enclosed in a specially designed shear box. The design of the machine and shear boxes was originally developed at the Massachusetts Institute of Technology and is essentially unchanged except for improvements resulting from experience gained through use. The machine is arranged to support the shear box rigidly and, by means of a system of levers and weights, to apply the vertical and horizontal loads to the specimen in any desired increments, ranging from 0.10 to 15.00 kg per sq cm for the vertical and 0.02 to 14.50 kg per sq cm for the horizontal. The machine in use is shown in Fig. 11.

The shear box (Fig. 12) is made in two parts: an upper one, movable in a horizontal plane; a lower one, fixed. An opening 6.00 cm (2.362 inches) square extends through the upper part and into the lower for the specimen and its accessories. A cross-section of the box with a specimen in place is shown in Fig. 13. Porous stones are placed above and below the specimen to allow free drainage when consolidation is to be produced during the test (delayed test). Impervious brass plates are substituted for the stones when the test is to be performed without allowing appreciable consolidation to take place (quick test). The stones or plates have saw-tooth-shaped grooves in the faces adjacent to the specimen; these grooves serve to distribute the shearing stresses uniformly over the entire surface of the specimen in an attempt to develop its full shearing resistance. A thick, close-fitting piston is placed in the upper part of the box on top of the upper stone and the vertical load applied directly to it.

A specimen to be tested is cut and trimmed 6.00 cm square and 2.40 cm thick to fit the opening in the box, and the top and bottom faces shaped to fit the grooves in the stones or plates. The trimmed specimen is placed between the desired plates, other accessories attached in their proper places, and the assembled box set-up on the loading machine shown in Fig. 11. Two extensometers, for measuring the vertical movement of the piston and horizontal displacement of the upper part of the box, are then attached in their proper brackets.

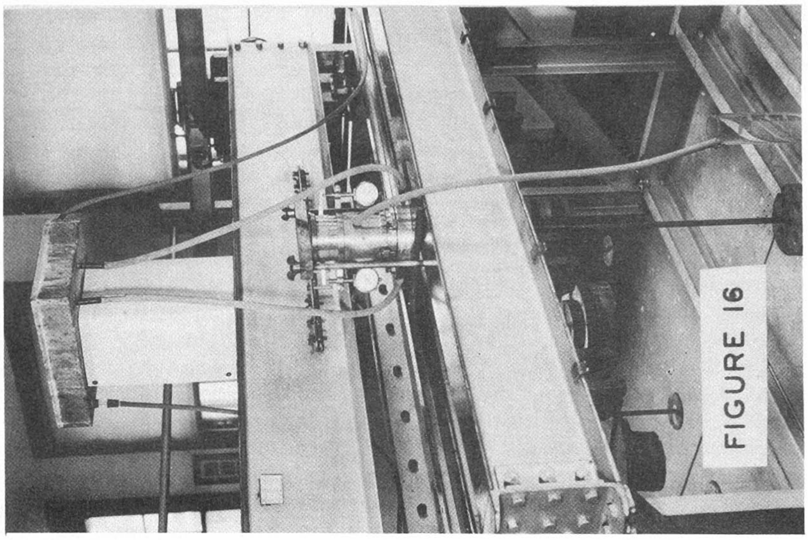


FIGURE 16

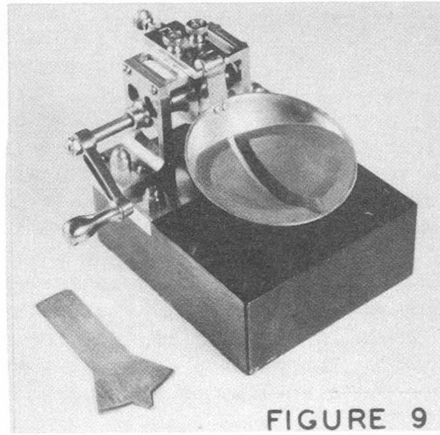


FIGURE 9

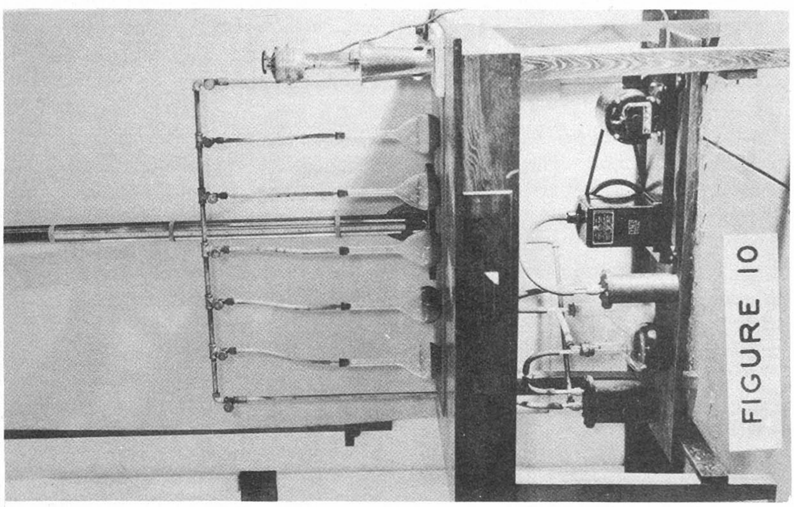


FIGURE 10

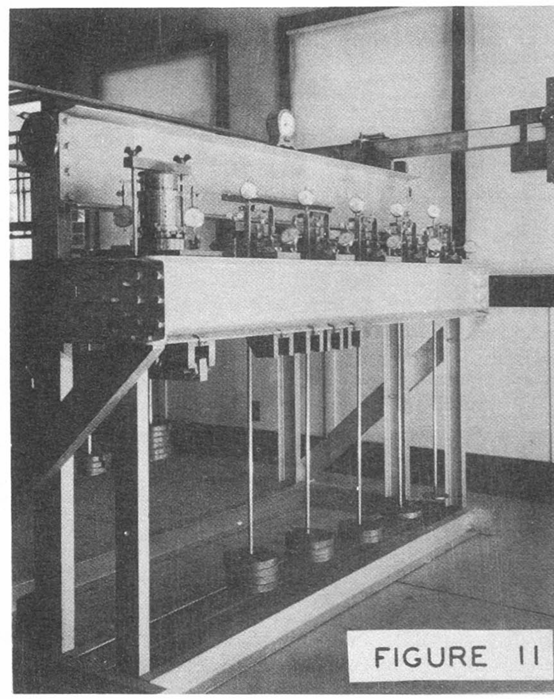


FIGURE 11

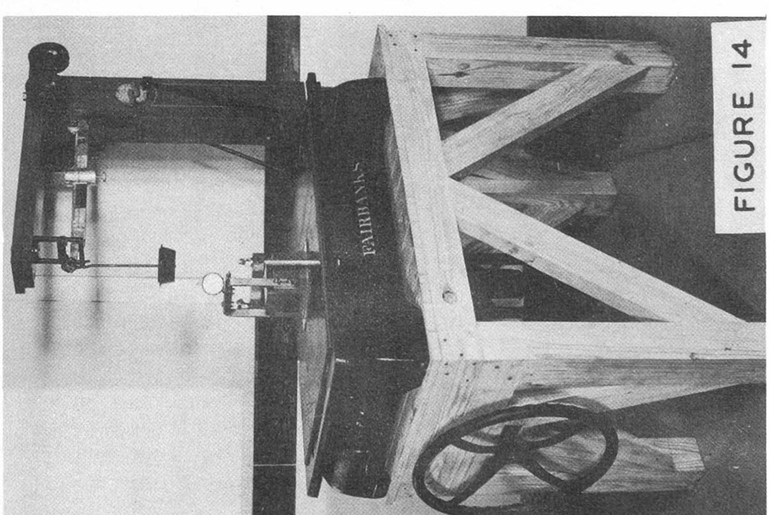


FIGURE 14

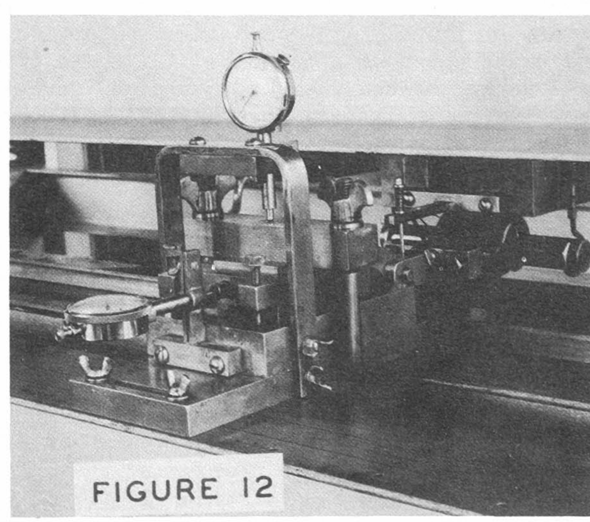


FIGURE 12

The delayod shear test is conducted on consolidated specimens, applying the increments of shearing load so that failure will occur in about 90 minutes. Thus, adjustments within the specimen may occur during the test and the full resistance in shear of the material be developed. A stress-strain curve for each specimen (three or more specimens under as many different vertical loads are usually tested of each sample) is plotted to obtain the stress at which failure occurred. An arithmetic plot of the shearing stress at failure against the corresponding vertical stress for each of the specimens results in a straight line. The slope of this line is the tangent of the angle of internal friction; the extrapolated intersection of this curve with the ordinate of zero-vertical-stress determines the cohesive strength of the material in its condition at the beginning of the test.

The quick shear test is conducted in a manner similar to that just described, except that a short schedule for the application of the shearing load is used, not longer than four minutes; thus, no additional consolidation of the specimen will occur: the ultimate shearing strength of the material in situ is thus determined. The "squeeze test", developed by Dr. Jurgenson (7) and performed with the apparatus shown in Fig. 14, may also be used for determining the ultimate shearing strength of a foundation material. The results of these tests are used in applying the Jurgenson method of analysis for determining the stability of a foundation material against lateral displacement under pressure.

Consolidation. The compressibility, and to a certain extent the strength, of a soil involved in a foundation problem is estimated by the application of the Terzaghi Theory of Consolidation using factors determined by the consolidation test of specimen of it. The apparatus used for this test of laterally confined specimen is shown in Fig. 15. The basic design of the apparatus was developed by Dr. Casagrande and has been well described elsewhere (1) (8) so that a discussion of its uses, arrangement, and the data obtained from the test, will not be entered into here. However, it may be of interest to note that two types of machines are used for applying the increments of load: the first, for a highly compressible soil for which sizeable movements of the piston may be expected, consists of the system of weights and levers arranged on the shear machine, Fig. 11; and the second, for moderately to slightly compressible soil, is the scale and jack arrangement shown in Fig. 14, which is easier to operate but requires adjustment for piston movements of greater than 0.01 inches.

Permeability. The permeability of silt or clay soils, required for the solutions of problems involving the flow of water through such materials in earthen structures or foundations, is determined directly with the consolidation device shown in Fig. 15. The apparent success we have had with this apparatus has been very gratifying. The addition of the graduate standpipe, as shown, converts the consolidation apparatus into a variable-head permeameter; the hydrostatic pressure created in the standpipe causes a flow of distilled water through the confined specimen. The factors required for the application of Darcy's Law (9) to the conditions are measured directly and the coefficient of permeability, k, determined. The measured factors become: a, area of standpipe; L, length of soil specimen; A, area of specimen; and t, time for the initial head H_1 to decrease to H_2, when the Law is expressed as follows:

$$k = \frac{aL}{At} \log_e \frac{H_1}{H_2}$$

The coefficient is determined for a material at several void-ratios so that the relation between the two may be established. The determinations may be made simultaneously with the consolidation tests during the intervals between the complete consolidation under one increment of load and the application ot the next increment.

The permeability of sands, grain size not greater than 1.0 mm diameter, is determined with a modification of the old type consolidation device. A constant-head is substituted for the variable-head arrangement previously described. The use of this equipment enables the investigator to determine the relationship between the void-ratio and permeability, neglected by many. The arrangement of the apparatus is shown in Fig. 16. Results believed to be superior to those obtained from the horizontal capillarity test or those computed from grain size distribution curves have been obtained by this method. Materials having a grain size larger than the above limit may be analyzed by the method and apparatus described by Knappen and Philippe (5).

Special Equipment. In addition to performing the more or less standardized tests of soils, the Laboratory has the facilities for determining pressures exerted against dams and retaining walls by masses such as unconsolidated soils that exist in sediment-filled reservoirs; and for investigating and solving problems of seepage through earthen structures and their foundations. The apparatus for determining the pressures against dams and retaining walls consists of an open top chamber or tank, one side of which is formed by a movable plate. The plate is so arranged that its movement can be measured and controlled, and thrusts against it, horizontal and vertical, can be measured directly by means of scales. The apparatus is shown in Fig. 17. The apparatus shown in Fig. 18, for estimating the seepage through levees, dams, and their foundations, consists essentially of a flume 3 feet deep and 1 foot wide, one side of which is formed by glass panels.

General Remarks. Many types of soils are studied and analyzed in this Laboratory since its services are available to all of the U. S. Engineer Offices. One of the most interesting materials encountered has been a local soil known geologically as the Vicksburg Loess. It has been used successfully for the construction of two earthen dams at the Station, both of which are about 35-feet high. The physical

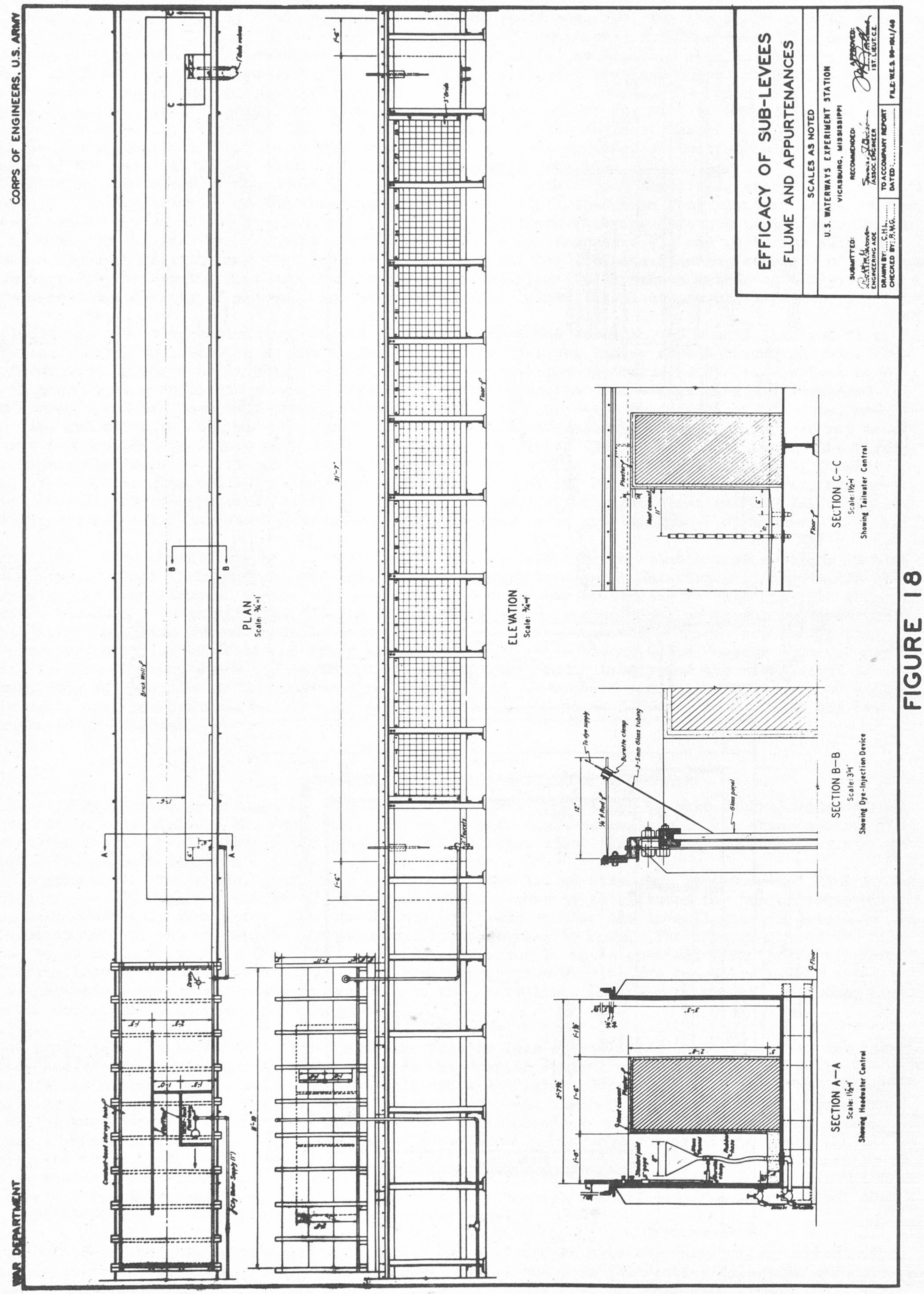

WAR DEPARTMENT
CORPS OF ENGINEERS, U.S. ARMY
PLAN
Scale: 3/4"=1'
ELEVATION
Scale: 3/4"=1'
SECTION A–A
Scale: 1½"=1'
Showing Headwater Control
SECTION B–B
Scale: 3"=1'
Showing Dye-Injection Device
SECTION C–C
Scale: 1½"=1'
Showing Tailwater Control
EFFICACY OF SUB-LEVEES
FLUME AND APPURTENANCES
SCALES AS NOTED
U.S. WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

FIGURE 18

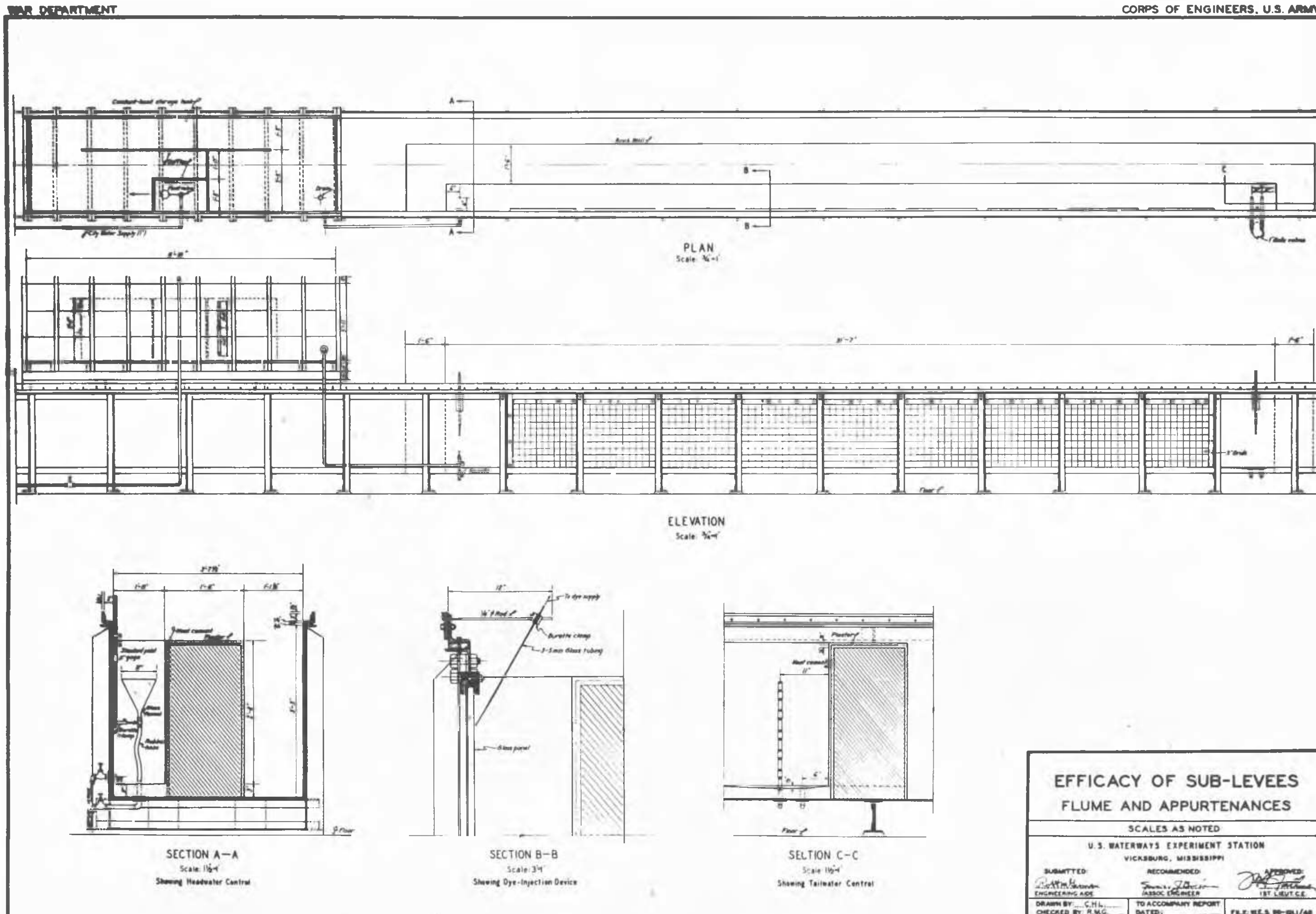


FIGURE 18

A-23

properties of this soil are given in the following table.

Depth of Sample Feet	Water content in situ	Atterberg Limits Per cent Liquid	Plastic	Shrinkage	Angle internal friction (Undisturbed)	Abs spec grav	Permea-bility* Cm per sec
12	23.7	29.4	27.3	23.5	23°	2.74	4.8×10^{-7}

*Void-ratio = 0.70; t = 20°C

Some of the investigations completed within the past eighteen months have been the design of a levee unit located in an extensive swamp in Illinois, which involved the checking and preventing the lateral displacement of a highly plastic clay foundation material; the investigation and application of the Jurgenson method of analysis to the foundations of three levee units of the Mississippi River System, the foundations of the first two failed in shear and the third, which was similar in every respect to the others, has been stable; the design and redesign of slopes 50 feet in height, formed of loess from the vicinity of Memphis, Tennessee, both in the undisturbed and compacted newly placed condition; determination of the coefficient of permeability of sandstone rock, using a wide range of hydrostatic pressures, which tends to show that this factor remains unchanged when the state of voids remains stable regardless of the hydrostatic pressures developed; and the determination of lateral pressures exerted against dams or retaining walls by new hydraulically deposited sand, silt, and clay.

BIBLIOGRAPHY

1. "Improved Soil, Testing Methods", G. Gilboy, E. N. R., May 21, 1936.
2. "The Hydrometer Method for Mechanical Analysis of Soils and Other Granular Materials", A. Casagrande, Cambridge, Mass., 1931.
3. "Die Plastizitat der Tone", A. Atterberg, Internationale Mitteilungen für Bodenkunde, 1911, Heft 1.
4. "Research on the Atterberg Limits of Soils", A. Casagrande, Public Roads, Vol. 13, No. 8, 1932.
5. "Practical Soil Mechanics at Muskingum - IV", T. T. Knappen and R. R. Philippe, E. N. R. Vol. 116, No. 19.
6. "Notes on Soil Mechanics", G. Gilboy, Mass. Inst. Tech., Cambridge, Mass., 1930, p. 2.
7. "The Application of Theories of Elasticity to Foundation Problems", and Shearing Resistance of Soils", L. Jurgenson, Journal, Boston Soc. C. E., Vol. XXI, No. 3, July 1934.
8. "Recent Developments in Soil Testing Apparatus", P. C. Rutledge, Journal, Boston Soc, C. E., Vol. XXII, No. 4, Oct. 1935.
9. "Soil Mechanics Research", Glennon Gilboy, Proceedings, Am. Soc. C. E., Vol. 57, No. 8.

No. A-24 THE SOIL MECHANICS LABORATORY AT THE TECHNISCHE HOCHSCHULE IN VIENNA, AUSTRIA

Note: Numbers in parentheses refer to Bibliography at the end of this paper.

The laboratory is located on the ground floor and in the basement of the main building of the Technische Hochschule in Vienna IV, Karlsplatz 13. Established 1929.

In charge, Professor Dr. Karl von Terzaghi; four permanent assistants; two to five volunteers (post-graduates and visiting engineers); one mechanic. The laboratory is equipped for both research and consulting work.

Total area of laboratory rooms 340 sq m. Humid room 20 sq m. Humidification by sprinklers. Thermostat room 21 sq m. Electric temperature control in the thermostat room.

The equipment includes the following apparatus: Wiegner apparatus and density hydrometers for wet-mechanical analysis. A set of standard sieves for sieve analysis of dry powders.

1 Casagrande liquid limit device.

1 Krey shearing device, 6 lever devices for pre-consolidation of the samples for shearing tests.

1 Hvorslev ring shearing apparatus (Fig. 1. See also Paper No. D-11 in this volume).

3 Terzaghi Oedometers (consolidation apparatus) equipped for simultaneous direct permeability tests.

6 Casagrande Oedometers for simultaneous consolidation and permeability tests (Fig. 2).

1 Apparatus with sliding weights for simple, unconfined compression tests on 1 in samples.

1 Apparatus with hydraulic press for simple, unconfined compression tests on 2 in samples.

4 direct load apparatus for simple compression tests at constant load over long periods.

1 Apparatus for tri-axial compression tests, operating on the vacuum principle, greatest all-sided pressure 0.5 atm. (28) (Fig. 3).

1 Apparatus for tri-axial compression tests under oil-pressure up to 10 atm.

1 Swedish cone device for measuring penetration from point to point over full length of cylindrical