Method of Test for Strength Parameters of Soils by Triaxial Compression Tests

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MEMORANDUM

TO: James H. Havens
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SUBJECT: Triaxial and Consolidation Test Procedures

Attached you will find descriptions of the test procedures currently in use in the Division of Research for performing triaxial compression tests and consolidation tests on soils. These procedures have been written in general terms and require the use of no specific brand of test equipment. In addition, the test methods embody those features of laboratory triaxial and consolidation testing that are currently considered to be more or less routine. In this sense, then, these test methods represent the nominal "standard" procedures.

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STRENGTH PARAMETERS OF SOILS
BY TRIAXIAL COMPRESSION TESTS
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SCOPE

1. This method of testing enables the determination of the strength parameters of soils. The methods described are the consolidated undrained triaxial compression test—with or without pore pressure measurements—and the unconfined compressive strength test. The parameters obtained are the angle of internal friction, $\phi$, the cohesion, $c$, and the unconfined compressive strength. The values so obtained may be employed in the design and analysis of earth structures—with consideration of the accepted criteria of stability and safety.

APPARATUS

2. (a) Loading Device. The loading device may consist of a platform weighing scale, a jackscrew, and a yoke; a hydraulic ram; or other compression systems having sufficient capacity and sensitivity. The Division of Research uses a frame equipped with a variable-speed, motor driven screw (see Figure A-1). The test chamber, containing the specimen, moves upward against a fixed piston. The motor should be capable of effecting deformation rates from a minimum of 0.0002 inches per
Figure A-1. Loading Frame with Proving Ring
minute to approximately 0.0500 inches per minute.

(b) Load Measuring Device. The load-measuring device may consist of a proving ring capable of measuring axial loads to the nearest 0.1 pound. When a proving ring is used, it is normally mounted on the outside of the test chamber. An electrical load cell may also be used to measure the axial loads applied to the test specimen (see Figure A-2). The load cell may be mounted inside the test chamber and thus minimize the error in the measured load due to the friction between the loading piston and the bushing where the piston enters the chamber. When a load cell is used, the following accessory electronic equipment is needed to indicate the loads:

(1) Amplifier. The electrical signals from the load cell are increased by this device so that they are sufficiently large to be detected by a digital voltmeter or strip chart recorder.

(2) Power Source. A constant-voltage power source is required to excite the load cell or pressure transducer.

(3) DC Bridge Balance. The device is used to balance the electrical circuits of the measuring system.
Figure A-2. Loading Frame with Accessory Electronic Equipment
(4) Digital Voltmeter or Strip Chart Recorder. These devices are used to indicate the load or pressure.

(c) Deformation Indicator. The deformation indicator may be a dial extensometer graduated to 0.001 inches and having a travel of approximately 20 percent of the length of the test specimen or other measuring devices meeting these general requirements.

(d) Trimming Equipment. This equipment includes a frame (see Figure A-3), appropriate trimming and carving tools, vernier calipers capable of measuring the dimensions of the specimen to the nearest 0.01 inches, a sample cutter, an end-trimming device, and a sample extruder.

(e) Pore Pressure Device. This device consists of a closed manometer gage and a null indicator or pressure transducer. When pressure transducers are used, the same electronic equipment used to monitor loads, as measured by the electrical load cell, may be used.

(f) Drying Oven. A thermostatically controlled drying oven capable of maintaining a temperature of 230± 9°F (110 ±5°C) for drying moisture content specimens is required.
Figure A-3. Specimen Trimming Equipment
(g) Balances. The balances shall be suitable for weighing soil specimens to the nearest 0.01 grams.

(h) Pressure Chamber. The pressure chamber (see Figures A-4 and A-5) is used to contain the test specimen and the confining fluid during the test. Accessory parts associated with the test chamber include: sample base plate, porous stone, two lubricated base plates, four small rubber O-rings, stopcock valve, sample header, two large rubber O-rings, Saran tubing for drainage, top cap, load piston, rubber membrane, filter paper strips, dial rest, and dial holder.

(i) Miscellaneous Apparatus. Miscellaneous equipment required includes a vacuum pump and compressed air supply with associated regulators and pressure gages, a membrane expander, moisture content cans, and data sheets, as required.

PREPARATION OF TEST SPECIMENS

3. (a) Specimen Size. Specimens should have a minimum diameter of 1.3 inches, and the largest particle contained within the test specimen should be smaller than one-tenth of the specimen diameter. For specimens having a diameter of 2.8 inches or larger, the largest particle size should be smaller than one-sixth of the specimen diameter. If, after completion of a test of
Figure 4-4: Close-up view of pressure chamber
Figure A-5. Schematic Drawing of Triaxial Test Apparatus
an undisturbed specimen, it is found that larger particles are present, appropriate notations should be made in the report of the test data. The height-to-diameter ratio shall be between 1.25 and 3. The height and diameter of the specimen shall be measured to the nearest 0.01 inch using a vernier caliper or other suitable device.

(b) Undisturbed Specimens. Undisturbed specimens may be prepared from large undisturbed samples or from samples secured in accordance with the Method for Thin-Walled Tube Sampling of Soils (ASTM Designation: D 1587). When the tubes are received in the laboratory, the samples are extruded using a hydraulic jack mounted in a horizontal position (see Figure A-6). Moisture content samples are taken and the sample is cut into specimens of the desired length. The soil is identified by ASTM Tentative Recommended Practice for Description of Soils (Visual-Manual Procedure) and is dipped in wax and stored in a cool place until ready for testing.

Tube specimens may be tested without trimming, except for the squaring of ends, if conditions of the sample justify this procedure. If trimming is necessary, the specimen should be handled carefully to prevent disturbance, changes in cross section, or loss of moisture.
Figure A-6. Hydraulic Jack for Extruding Shelby Tube Samples and Vacuum Auger for Preparing Remolded Specimens
content. The trimming of specimens, whenever possible, should be done in a humidity-controlled room and effort should be made to prevent any change in moisture content of the soil.

The frame of the sample trimmer used by the Division of Research is constructed so that the cylindrical cutter is moved vertically without any horizontal movement. The inside diameter of the cutter is approximately 0.005 inches larger than the desired diameter of the test specimen, except for a 1/8-inch length at the cutting end, where the diameter is equal to the specimen diameter. The sample is centered under the cutter, which is lowered to the desired position by loosening wing nuts. After positioning, the cutter is slowly pushed down into the sample. Concurrently, the excess soil is trimmed away by using carving knives, etc. When the frame is lowered to its final position and the cutter is filled with the specimen, the cutter is removed and the specimen extruded with the extrusion block. To insure the least possible disturbance, the cutter is lubricated with a lightweight oil. If the surface of the extruded specimen is not smooth, bits of the soil trimmings are used to fill any voids. After this, the cutter may again be gently pushed over the specimen to once again insure a proper-sized specimen.
The specimen is then placed in the end-trimming device and trimmed so that the ends are perpendicular to the longitudinal axis of the uniform circular specimen.

Several measurements of the diameter and height of the specimen are made and the weight of the test specimen is determined. If the entire test specimen is not to be used for determination of moisture content, a representative sample of cuttings is secured for this purpose and placed immediately in a covered container.

(c) Remolded Specimens. Specimens may be prepared from a failed, undisturbed specimen or from a disturbed sample. The disturbed material may be formed in a mold of any size; the method of molding and compaction may be varied to produce the desired density, moisture content, and soil structure. If the specimens are not molded to the desired size, the soil trimming equipment used to trim undisturbed samples can also be used to trim specimens from the remolded material.

Remolded specimens can also be prepared from undisturbed samples by an extrusion process. The soil is mixed in a vacuum and forced by augers through a die.
of desired size and shape. Cylindrical specimens up to three inches in diameter can be made by this process. Mixing in a vacuum produces a high degree of uniformity and saturation. To prepare such specimens the soil is first pulverized and passed through a Number 4 sieve. Water is added to the entire sample, to bring the moisture content to the desired value, and mixed for a few minutes by hand. The mixture is then run through the extrusion machine at least twice to insure complete and uniform mixing. The material is again run through the extrusion apparatus, and the rod of extruded soil is cut into specimens of the desired lengths and immediately immersed in melted wax for protection until testing. When the desired number of specimens is obtained, more water can be added to the soil-water mixture and the mixing and extrusion process repeated. This permits the preparation of a number of specimens over a range of moisture contents.

TEST PROCEDURE

4. (a) The pedestal is prepared as follows: 1) a saturated porous stone is placed in the recession of the pedestal, 2) strips of filter paper are placed over the porous stone, and 3) a polished plexiglass or teflon disk, slightly larger in diameter than the
specimen, is placed over the porous stone on the pedestal. The disk is coated with a thin film of silicone grease. The coated disk is used to reduce end friction between the specimen and the end cap and thus allow for more uniform deformation. The specimen is then placed on the coated disk, and the strips of filter paper are folded up along the sides of the specimen to the top of the specimen in order to provide drainage paths during the consolidation period.

(b) Using a vacuum membrane-expander, a thin, leak-proof membrane is placed over the specimen. Two rubber O-rings are placed around the membrane at the elevation of the pedestal to provide a positive seal. A coated, polished disk is placed on the specimen and then a header or top cap is placed over this. Two rubber O-rings are then placed around the membrane at the header to provide a positive seal at the top of the specimen. When the unconfined compression test is being run, the O-rings at the top cap and at the pedestal are not required. The hollow plexiglass cylinder is placed on the base, and the top cover is secured by means of the three vertical rods and nuts. Large O-rings are used to form a pressure seal between the cylindrical chamber and the base and the top cover. The loading
piston is then placed into the chamber through the bushings and lowered until it enters, but does not touch, the recess in the top end cap.

(c) The test chamber containing the specimen is placed in the loading frame and filled with water to an elevation approximately one inch above the O-rings around the top header cap. To saturate the drainage lines prior to beginning the test, a vacuum is applied to one drainage line while the end of the other is submerged in a beaker of water. This removes air from between the sample and membrane and draws water from the beaker into the drainage lines. The vacuum line is then disconnected and a burette is attached to the line. Water is allowed to flow back from the burette through the drainage lines until it is apparent that all air bubbles have been removed. A small pressure (approximately two pounds per square inch) is applied to the fluid in the test chamber during this process to prevent water from entering the space between the sample and membrane. The pore pressure line is then connected to the pore-pressure measuring device. If pore pressure measurements are not required, the measuring device does not need to be connected.

In the unconfined compressive test, the procedures of the above paragraph are not used.
(d) The confining pressure is applied to the specimen by means of the pressure regulator. Concurrently, a back-pressure is applied to the top of the burette by means of another pressure regulator. The consolidation pressure achieved is the difference between these two pressures. One of the specimens of the triaxial series is consolidated under a pressure approximately equal to the in situ confining pressure (estimated by knowing the unit weight and depth below the surface from which the sample was obtained). Other confining pressures are used in the series to obtain differences in the principle stresses in order to plot the Mohr's circles. A back pressure (usually 30 pounds per square inch) is applied overnight to insure that the specimen is saturated.

In the unconfined compressive test, the procedures of the above paragraph are not used.

(e) Before the axial load is increased, the valve between the chamber and the burette is closed so that the specimen is sheared in an undrained condition.

(f) The loading device is started and allowed to run a few minutes at the desired testing speed in order to compensate for any piston friction and (or) upward thrust on the piston due to chamber pressure.
The load- and deformation-measuring devices are zeroed when the piston makes contact with the top header.

In the triaxial test, the strain rate used in applying the axial load is one or two percent per hour. This insures a failure time of not less than four hours and in most cases up to approximately eight hours. This is sufficient time to permit equalization of pore pressures within the specimen. Readings of the deformation, applied load and pore pressure are taken at approximately five-minute intervals at the beginning of the test and at 30-minute intervals thereafter.

The strain rate used in the unconfined test is approximately 0.5 percent per minute. Readings of the load and deformation are taken at 0.005-inch intervals up to a deformation of about 0.2 inch and thereafter at 0.01-inch intervals until failure occurs.

The test is continued until the load decreases or remains essentially constant. Some specimens will yield under nearly constant stress while the load continues to increase slightly due to the increasing cross-sectional area. An examination of a few readings will indicate whether or not the maximum stress has actually been reached.

(g) After failure, all pressures are released and the confining fluid is drained from the test chamber.
The testing apparatus is disassembled—being careful not to disturb the failed specimen. The specimen is examined and the mode of failure is sketched for future reference. The specimen is weighed and placed in an oven to dry in order to determine the moisture content and unit weight.

CALCULATIONS

5. (a) Assuming that the specimen strains equally in all directions under the confining pressure, the length of the specimen after consolidation (just prior to shearing) may be determined by means of a trial-and-error method using the following equation:

\[ AL - \Delta V = \pi \left( R - \frac{RA}{L} \right)^2 (L - \Delta L) \]

where

- \( A \) = cross-sectional area of specimen as determined by physical measurements,
- \( L \) = length of specimen as determined by physical measurements,
- \( \Delta V \) = volume change as measured by the burette,
- \( R \) = radius of the specimen as determined by physical measurements, and
- \( \Delta L \) = change in length of specimen during consolidation.

An alternative method of obtaining the area (volume) of the specimen after consolidation is to measure the change
in height with a cathetometer and to calculate the radius of the specimen.

(b) The axial strain, $\varepsilon$, for a given applied load is calculated as follows:

$$\varepsilon = \Delta \ell \frac{1}{\ell_0}$$

where $\Delta \ell = \text{change in length of specimen as determined from the deformation indicator}$, and

$\ell_0 = \text{length of specimen after consolidation}$.

(c) The average cross-sectional area, $A$, for a given applied load is calculated as follows:

$$A = \frac{V_0}{\ell_0 - \Delta \ell}$$

where $V_0 = \text{volume of specimen after consolidation (just prior to shearing)}$.

The area, $A$, may alternatively be calculated from dimensions obtained by direct measurement by means of a cathetometer when the surfaces of the specimen are measureable.

(d) The deviator load per unit area, $\sigma_a$, for a given applied load is:

$$\sigma_a = \frac{P}{A}$$

where $P = \text{the applied deviator load}$, and $A = \text{the corresponding average cross-sectional area}$.
(e) Graphs. A graph should be prepared to show the relationship between the pore pressure and the unit strain, if pore pressures were measured. A graph should also be drawn to show the relationship between the unit deviator stress and the unit strain—plotting the unit deviator stress values as the ordinate and the unit strain values as the abscissa.

The maximum value of the load per unit area or the load per unit area at 20 percent strain, whichever is obtained first, is reported as the unconfined compressive strength. For the triaxial test, the maximum value of the deviator stress \( \sigma_d = \sigma_1 - \sigma_3 \) is selected and used to construct the Mohr's circles. When all Mohr's circles have been plotted, a line is drawn which is most nearly tangent to all the circles. The intersection of this line with the ordinate axis is the cohesion value, c, and the angle between this line and the horizontal is the angle of internal friction, \( \phi \).

REPORT

7. The report shall include the following:

1) The unconfined compressive strength or the cohesion and the angle of internal friction.

2) Type of test performed—that is, unconfined compressive test, consolidated undrained triaxial
test with pore pressure measurements, or consolidated undrained triaxial test without pore pressure measurements.

3) Type and shape of specimen—that is, undisturbed, remolded, cylindrical, or prismatic.

4) Height-to-diameter ratio.

5) Visual description.

6) Initial density, moisture content, and degree of saturation.

7) For the unconfined compressive test, the average strain at failure.

8) Average rate of strain to failure, in percent.

9) Remarks—note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained.
Method of Test for

CONSOLIDATION PARAMETERS OF SOILS
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SCOPE

1. This method of testing enables the evaluation of consolidation parameters of soils for use in determining the time rate and magnitude of settlement of soils under load. The test conditions are such that the test specimen is completely confined laterally, freely drained in the vertical direction, and subjected to a vertical, axial load.

APPARATUS

2. (a) Loading Device. The loading device may consist of a loading frame with a counterbalanced lever system (see Figure B-1), a platform scale, or a hydraulically controlled apparatus (see Figure B-2). The apparatus should permit the application of a given load increment without impact within approximately 1/2 second. It should be capable of maintaining specified loads indefinitely, within approximately 1/2 percent of the applied load, while permitting increasing vertical compression of the sample.

The major control components of the hydraulic loading apparatus are:

(1) Piston-diaphragm System. The load is applied to the specimen through the piston-diaphragm system.
Figure B-1. Counterbalanced Lever System Loading Frame.

Figure B-2. Hydraulically Controlled Loading Device.
(2) Air Regulators. The air pressure acting on the piston, and consequently the load applied to the sample, is controlled by the air regulators. A continuous supply of air is required. At any given setting, the regulator will pass a constant air pressure, regardless of variations in supply pressure. The precision at low pressures is increased by the use of a high pressure regulator attached between the low pressure regulators and the supply pressure. The stability of the regulators depends upon internal bleeding of air and the amount of air bled will approach 0.2 to 0.4 standard cubic feet per minute.

(3) Pressure Gauges. The pressure gauges are 8 1/2-inch precision test gauges with a repeatability of 1/4 to 1/2 of one percent. The gauges are calibrated in pounds per square inch and in tons per square foot on 2.50-inch and 4.44-inch specimens. They are provided with a reflector strip to eliminate parallax in reading. One gauge is used to record pressure passed by the air regulators in the range from 0 to 10 pounds per square inch and another for pressures in the range from 0 to 100 pounds per square inch.
(4) Control Values. A toggle (load) valve controls the application of pressure to the piston. The toggle valve is normally open during testing. It is closed only when it is necessary to change the load on the sample in order to maintain the existing load on the sample during the short interval of time necessary to reset the air regulator for the new load. When the toggle valve is reopened, the new load is applied instantaneously.

(b) Consolidometer. The consolidometer shall completely and rigidly confine the specimen in the lateral direction (see Figure B-3). The diameter of the consolidation ring shall be determined by the common size of undisturbed tube samples received for test or by the maximum sized particles in compacted specimens. The minimum specimen diameter-to-thickness ratio should be 2.2. The Division of Research normally uses specimens 2 1/2 or 2 1/4 inches in diameter by one inch nominal thickness. The consolidation ring should be made of a noncorrosive brass with the inner surface coated with teflon, as shown in Figure B-3.

(c) Porous Stones. Porous stones of suitable porosity and incompressibility shall be used at the top and bottom of the test specimen in order to transmit the load to the specimen and still permit free drainage. The stones may be made
Figure B-3. Schematic Drawing of Consolidometer.
from fine grade alundum. The upper porous stone is approximately 0.1 inch smaller in diameter than the consolidometer and is seated in a teflon loading cap as shown in Figure B-3. The loading cup has a clearance of less than 0.005 inches with the consolidometer ring and will fall through the ring under its own weight. The tolerance is close enough, however, that there is no tendency for soil to be extruded between the ring and the load cap, even when testing the softest of materials.

(d) Moist Room. Specimens should be stored and prepared in a moist room in order to minimize lose of natural moisture by evaporation.

(e) Deformation Indicator. The deformation indicator may be a dial extensometer graduated to 0.0001 inches and having sufficient travel to measure the expected vertical compression of the specimen.

(f) Trimming Equipment. This equipment includes a frame (see Figure B-4), appropriate trimming and carving tools, vernier calipers capable of measuring the dimensions of the specimen to the nearest 0.01 inches, a sample cutter, an end-trimming device, and a sample extruder.

(g) Drying Oven. A thermostatically controlled drying oven capable of maintaining a temperature of 230± 9°F (110 ±5°C) for drying moisture content specimens is required.
Figure B-4. Specimen Trimming Equipment.
(h) Balances. The balances shall be suitable for weighing soil specimens to the nearest 0.01 grams.

(i) Miscellaneous Equipment. Miscellaneous equipment required include moisture content cans, spatulas, wax heater, and data sheets.

PREPARATION OF TEST SPECIMENS

3. (a) Undisturbed Specimens. Undisturbed specimens may be prepared from large undisturbed samples or from samples secured in accordance with the Method for Thin-Walled Tube Sampling of Soils (ASTM Designation: D 1587). When the tubes are received in the laboratory, the samples are extruded using a hydraulic jack mounted in a horizontal position. Moisture content samples are taken and the sample is cut into specimens of the desired length. The soil is identified by ASTM Tentative Recommended Practice for Description of Soils (Visual-Manual Procedure) and is dipped in wax and stored in a cool place until ready for testing.

Tube specimens may be tested without trimming, except for the squaring of ends, if conditions of the sample justify this procedure. If trimming is necessary, the specimen should be handled carefully to prevent disturbance, changes in cross section, or loss of moisture content. The trimming of specimens, whenever possible, should be done in a humidity-controlled room and effort should be made to prevent any change in moisture content of the soil.
(b) Remolded Specimens. Specimens may be prepared from a failed, undisturbed specimen or from a disturbed sample. The disturbed material may be formed in a mold of any size; the method of molding and compaction may be varied to produce the desired density, moisture content, and soil structure. If the specimens are not molded to the desired size, the soil trimming equipment used to trim undisturbed samples can also be used to trim specimens from the remolded material.

(c) Use the material trimmed from the sample to determine the natural moisture content (based on dry weight) and the specific gravity in accordance with the Method of Test for the Specific Gravity of Soils, ASTM Designation: D 684. The initial wet weight of the specimen, and its volume, is determined from the diameter and height of the consolidation ring and the weight of the consolidation ring and the specimen.

(d) The liquid limit (ASTM Designation: D 423) and the plastic limit (ASTM Designation: D 424) are useful in identifying the soil and in correlating the results of tests on different specimens. These tests are also performed on the trimmings from the samples.

PROCEDURE

4. (a) The porous stones should be saturated so as not to absorb water from the test specimen. All surfaces of the
consolidometer which are to be enclosed should be moistened. After assembling the consolidometer, the consolidation ring and specimen and the porous stones are encased in a loose fitting plastic or rubber membrane to prevent evaporation or the movement of air around the specimen.

(b) The consolidometer is then placed in the loading device and a seating load of 100 pounds per square foot (50 grams per square centimeter) is applied. Adjust the micrometer dial gauge for the initial or zero reading. For very soft soils a seating load of 50 pounds per square foot (25 grams per square centimeter) or less is desirable.

(c) The consolidation pressure on the specimen should be increased by a suitable succession of load increments until a linear relationship between the thickness and the log pressure becomes apparent, or until the maximum pressure is at least twice that anticipated in the soil under the combined overburden and structural loads. Normally, pressure increments are added so that the total applied pressure will be approximately \(\frac{1}{32}, \frac{1}{16}, \frac{1}{8}, \ldots, 1, 2, 4, 8, \ldots\) tons per square foot. Smaller increments may be desirable on very soft samples.

(d) For each successive pressure increment, record the thickness, or change in thickness, of the specimen at such intervals of total time after the instant of loading that time-
consolidation curves may be plotted with sufficient accuracy; for example, approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 minutes, 1, 2, 4, 8 hours etc. Readings should continue at least until the slope of the characteristic linear, secondary portion of the consolidation-log time curve is apparent. For soils which exhibit a slow rate of primary consolidation, loads should be permitted to act on the specimen for at least 24 hours, and, in extreme cases or where secondary consolidation must be evaluated, much longer before the next load increment is applied.

(e) When rebound or unloading characteristics are desired, the specimen will be unloaded in double increments, and in reverse order, used in the loading sequence. Specimen thickness, or change in thickness, readings should be obtained over a period of time as indicated above.

(f) An alternative loading, unloading, and reloading schedule may be used if it better reproduces the construction stress changes, or results in a better definition of some part of the void ratio-pressure curve, or aids in interpreting the field behavior of the soil. The alternative schedule should be clearly indicated in the test report.

(g) If the test is performed on an undisturbed sample that was saturated under field conditions or obtained from below the water table, it should be inundated after the seating
load is applied. Samples also may be inundated at loads that simulate inundation under future field conditions. In such cases the load at inundation and any resulting effects, such as expansion or increased settlement, should be noted in the test report.

(h) At the completion of the test, the entire sample is removed from the consolidometer, weighed and oven dried to obtain the weight of solids.

CALCULATIONS

5. (a) A graph of the specimen thickness, or change in thickness, versus log time should be prepared for each increment of load or pressure as the test progresses. This is necessary to give an indication of the time to add the next load increment.

(b) The deformation, or specimen thickness, representing 100 percent primary consolidation for each load increment is determined as the intersection of a straight line through the points representing the final readings and which exhibit a straight line trend and a flat slope and a straight line tangent to the steepest part of deformation-log time curve.

(c) To find the deformation representing zero percent primary consolidation, determine the difference between deformations at any two times that have a ratio of 1 to 4 on
the early portion of the deformation (thickness)-log time curve. The deformation or thickness corresponding to a zero percent hydrodynamic consolidation is equal to the deformation corresponding to the earlier time less the difference in the deformations for the two selected times.

(d) The deformation corresponding to 50 percent hydrodynamic or primary consolidation for each load increment is equal to the average of the deformations corresponding to the 0 to 100 percent deformations. The time required for 50 percent consolidation under each load increment is found graphically from the deformation-log time curves.

(e) For each load increment, compute the coefficient of consolidation, \( c_v \) by

\[
  c_v = \frac{0.5H^2}{t}
\]

where \( H \) is the sample thickness in inches, \( t \) the time in minutes for 50 percent consolidation, and \( c_v \) is expressed in square feet per day.

(f) An alternative procedure for determining \( c_v \) requires that a graph of deformation versus the square root of time to be made. The central portion of the curve is approximately a straight line. The line is extrapolated back to zero time. The corresponding deformation represents zero percent
primary or hydrodynamic consolidation. A second straight line is drawn through this point so that the abcissa of this line are 1.15 times the abcissa of the straight line approximation of the central portion of the curve. The intersection of the new line with the deformation-square root of time curve corresponds to 90 percent primary consolidation. The deformation at 100 percent primary consolidation is 1/9 more than the difference in deformations between 0 and 90 percent consolidation. Similarly the deformation at 50 percent consolidation is 5/9 of the difference between that at 0 and 90 percent. The coefficient of consolidation can be found from the time of 90 percent consolidation by

\[ c_v = \frac{2.12H^2}{t} \]

where H is the sample thickness in inches, t the time for 90 percent consolidation in minutes, and \( c_v \) is expressed in square feet per day.

(g) Compute the initial void ratio, water content, unit weight, and degree of saturation.

(h) Compute the void ratio corresponding to 100 percent primary consolidation for each load. As an alternative, compute the percent settlement at 100 percent primary consolidation from the initial sample thickness for each load. Prepare a graph of void ratio (at 100 percent primary consolidation) versus log pressure.
6. The report shall include the following:

(a) Identification and description of sample, including the type of specimen—that is, undisturbed, remolded, or compacted.

(b) Initial moisture content.

(c) Initial unit weight.

(d) Initial degree of saturation.

(e) Specific gravity of solids.

(f) Condition of test—that is, natural moisture or inundated, and load of inundation.

(g) Deformation versus log time curves (optional, but desirable for organic and highly micaceous soil with appreciable secondary consolidation). As an alternative include deformation versus square root of time curves.

(h) Void ratio versus log pressure curve or percent settlement versus log pressure curve.

(i) Coefficient of consolidation versus log pressure curve.

(j) Remarks—note any unusual conditions or other data, such as special loading sequences, that would be considered necessary to properly interpret the test results obtained.