

PIT SLOPE MANUAL

supplement 3-4

SELECTED SOIL TESTS

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PIT SLOPE PROJECT

of the

Mining Research Laboratories

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THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

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ABSTRACT

This supplement describes soil testing methods relevant to open pit mining. For grain size analysis particles are sized by sieving and sedimentation. Consistency limits - shrinkage, plastic and liquid limits - are arbitrary measures of soil behaviour determined by standard soil mechanics procedures. Moisture density relationships when sample material is limited are determined using the Harvard miniature compaction apparatus. Triaxial tests with pore pressure measurement allow the effective stress parameters of soils to be determined; a triaxial cell with pressure monitoring instruments is used. The field vane shear test allows the undrained strength of saturated clay to be determined in situ.

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INTRODUCTION

1. This supplement covers selected soil testing methods which can be used to test overburden materials, or soil-like materials which may be found within rock formations in the form of gouge materials or highly altered and weathered layers.

2. Both laboratory and field tests are included. One kind of test relates to the physical properties of soils, and is mainly used for characterization and classification. The others are those performed to determine the strength properties of soils, for use in stability analysis.

3. The standards laid down by the American Society for Testing and Materials are not repeated in this supplement, and for their details the reader should consult the references.

GRAIN SIZE ANALYSIS

SCOPE

4. a. The grain size analysis provides a description of the quantitative distribution of particle sizes in a sample of soil or disintegrated rock.

b. The grain size analysis is usually presented as an ogive curve in which the abscissa represents the logarithm of the grain size, and the ordinate represents the percentage by weight of grains smaller than the sizes denoted. A typical grain size distribution curve is shown in Fig 2.

5. a. The shape of the curve and its position relative to the range of the diagram depends primarily on the type of the soil or rock, and on its geological history. It thus provides a valuable means of identification.

b. The size of the particles that constitute soils or disintegrated rocks may vary from blocks or boulders, to microscopic elements.

PREPARATION OF THE TEST SPECIMEN

6. Depending on the characteristics of the grain particles of the soil samples received from the field for particle size analysis the samples are prepared by one of the following methods:

a. If the coarse-grain particles are soft and pulverize readily in the dry method of preparation, or if the characteristics of the material may change greatly when dried the wet method of

preparation should be used. The wet preparation of soil samples is detailed in ASTM Designation: D 2217-66 (1).

b. The samples, however, are usually prepared by the dry method, detailed in ASTM Designation: D 421-58 (2).

PROCEDURE

7. a. The grain size analysis usually consists of two phases. The distribution of particles larger than 0.074 mm, ie retained on the No. 200 sieve, is determined by sieving, and that for sizes smaller than 0.074 mm is by a sedimentation or hydrometer analysis.

b. The procedures for the sieve and hydrometer analyses are detailed in ASTM Designation: D 422-63 (3).

8. a. If the soil sample contains an insignificant portion of particles smaller than 0.074 mm, often the case with cohesionless soils and disintegrated rocks, the hydrometer analysis can be omitted.

b. In this case the material is first dried in an oven and then sieved on a No. 10 (2.00 mm) sieve.

c. The portion of the material which passes through the No. 10 sieve is weighed and is brought into a water suspension. It is then placed on a No. 200 (0.074 mm) sieve and washed with tap water until the wash water is clear.

- d. The material remaining on the No. 200 sieve is then transferred to a suitable container, dried and weighed.
- e. A sieve analysis is then performed on this portion of the material by using successively sieves No. 20 (0.841 mm), No. 40 (0.420 mm), No. 140 (0.105 mm) and No. 200 (0.074 mm).

CALCULATIONS

9. a. A working sheet for the sieve analysis and a complete grain size distribution curve are shown in Fig 1 and Fig 2, respectively.
- b. The uniformity of a sample can be expressed by

the uniformity coefficient, U , which is the ratio of D_{60} to D_{10} ; where D_{60} is the particle diameter of which 60% of the sample weight is finer and D_{10} is the corresponding value at 10% finer.

- c. Provided that the obtained grain size distribution curve is smooth and without abrupt changes, the uniformity coefficient can be used to classify the sample. The following terms may be used for classification:

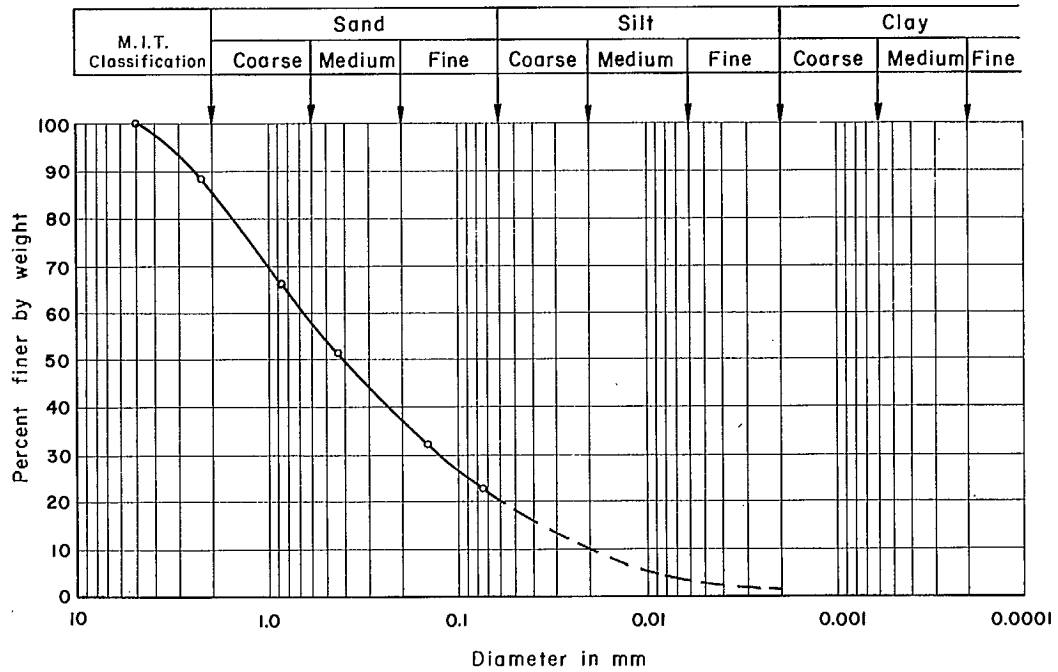
uniform if $U < 2$
 graded if $2 < U < 8$
 well-graded if $U < 8$

SIEVE ANALYSIS

Soil sample <u>silty sand: overburden</u>	Soil sample weight	Test No. <u>2</u>
_____	Container No. <u>33</u>	
_____	Wt. container +	Date <u>January 26, 1971</u>
Location <u>waste dump area</u>	dry soil, (g) <u>905.8</u>	
Boring No. <u>7</u> Sample depth <u>12 ft.</u>	Wt. container, (g) <u>402.2</u>	Tested by <u>W.G.</u>
Sample No. <u>5-3</u>	Wt. dry soil,	
Specific gravity, G_s <u>2.75</u>	W_s , (g) <u>503.6</u>	

Sieve No.	Sieve opening mm	Wt. sieve g	Wt. sieve + soil g	Wt. soil retained g	Percent retained	Cumulative percent retained	Percent finer
4	4.76	514.2	514.2	0	0	0	100
8	2.38	398.1	453.5	55.4	11.0	11.0	89.0
20	.84	370.3	483.6	113.3	22.5	33.5	66.5
40	.42	358.0	437.2	79.1	15.7	49.2	50.8
100	.149	398.2	492.4	94.2	18.7	67.9	32.1
200	.074	312.7	408.9	96.2	19.1	87.0	13.0
Pan	—	350.3	415.7	65.4	13.0	100.0	—
				$\Sigma = 503.6$	$\Sigma = 100.0$		

Fig 1 - Working sheet for sieve analysis.



$$D_{60} = 0.66 \text{ mm}$$

$$D_{10} = 0.02 \text{ mm}$$

$$\text{Uniformity coefficient, } U = \frac{D_{60}}{D_{10}} = \frac{0.66}{0.02} = 33$$

Classification of the sample : well-graded silty sand

Fig 2 - Grain size distribution curve.

DETERMINATION OF CONSISTENCY LIMITS AND INDICES

SCOPE

10. The consistency limits are associated with the changes in appearance and behaviour of cohesive soils in relation to changes in their moisture content. A cohesive soil undergoing a gradual change in its moisture content passes through various stages of consistency and thus different mechanical responses. The consistency limits give convenient breaking points between the stages. As the moisture content of a cohesive soil increases, the soil successively reaches the shrinkage, plastic, and liquid limits. These are expressed in terms of moisture content at the respective breaking points. The quantitative values of the limits are mainly functions of the mineralogical and grain size compositions.

DEFINITIONS AND PROCEDURES

11. a. The shrinkage limit, (w_s), is defined as the maximum water content at which a reduction in moisture will not cause a decrease in the volume of the soil mass.

b. The procedure which determines the shrinkage limit is given in the ASTM Designation: D 427-61 (4).

12. a. The plastic limit, (w_p), is the water content at the boundary between the semi-solid and plastic states. The water content at this boundary is arbitrarily defined as the lowest at which the soil can be rolled into threads 1/8 in.

(3.2 mm) in diameter without breaking into pieces.

b. The procedure which determines the plastic limit is given in the ASTM Designation: D 424-59 (5).

13. a. The liquid limit, (w_l), is the water content at the boundary between the plastic and liquid states. This is arbitrarily defined as that at which two halves of a soil cake will flow together for a distance of 1/2 in. (12.7 mm) along the bottom of the groove separating the two halves when the cup is dropped 25 times through a distance of 1 cm (0.3937 in.) at a rate of two drops per second.

b. The procedure for finding the liquid limit is given in the ASTM Designation: D 423-66 (6).

14. a. When the number of drops is known for at least three different levels of water content it is possible to plot a flow curve. This is a line on a semi-logarithmic scale with the water contents as abscissae on the arithmetic scale and the number of drops as ordinates on the logarithmic scale. The flow curve is then a straight line fitted as closely as possible through the three or more plotted points. A typical flow curve is shown in Fig 3.

b. The water content corresponding to the intersection of the flow curve with the 25-drop ordinate taken to the nearest whole number is the liquid limit w_l of the soil.

15. An indication of the range over which a

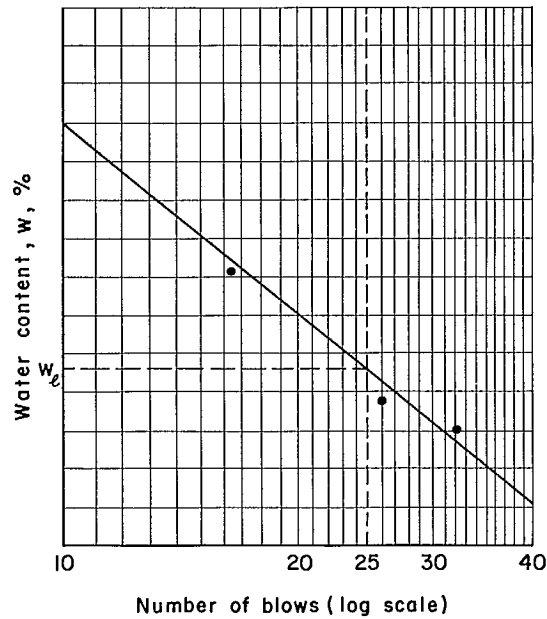


Fig 3 - Liquid limit flow curve.

soil possesses plasticity is given by the plasticity index, (I_p), defined as the numerical difference between the liquid limit and plastic limit:

$$I_p = w_L - w_p$$

16. a. The relative position of a real soil with respect to the liquid and plastic limits is described by the liquidity index, (I_L), defined as:

$$I_L = \frac{w - w_p}{w_L - w_p} = \frac{w - w_p}{I_p}$$

where, w = natural moisture content of a given soil.

b. For soils of liquid consistency, the liquidity index is greater than 1.0; for semi-solid and solid consistencies it is negative. The value of I_L between 0 and 1.0 indicates that the soil is plastic.

DETERMINATION OF MOISTURE - DENSITY RELATIONS OF SOILS

SCOPE

17. a. These methods cover the preparation of specimens for unconfined compression tests, for soil stabilization, and for determining the relationship between the moisture contents and densities of soils, when the amount of available soil is limited (7).

b. The proper combination of layers and compactive effort must be selected to meet the purpose of the investigation. This may require preliminary testing to obtain the proper combination.

c. Extreme care must be exercised in performing this test as errors will be significant because of the small size of the test specimen.

b. A metal tamper consists of a 0.500 ± 0.005 in. (12.7 ± 0.1 mm) diameter shaft, with a horizontally grooved handle on one end to accommodate the hand, and an enclosed compression spring. The compression of the spring is adjusted by a nut in such a way that when the specified force is applied, the spring will be further compressed with only a small increase in force. The tamper should be so constructed as to allow the substitution of different springs for various compactions. Compression springs of 20.0 ± 0.02 and 40.0 ± 0.02 lb (9.07 ± 0.01 and 18.14 ± 0.01 kg) are usually used as shown in Fig 4.

c. A manually operated free sliding ram is also included, it weighs 1.38 ± 0.01 lb (626 ± 5 g) and has a drop of 6.00 ± 0.02 in. (152 ± 1 mm) through a suitable guide rod; it is attached to a circular base 1.000 ± 0.005 in. (25.40 ± 0.13 mm) in diameter, as in Fig 5.

d. A suitable device holds the compacted soil in place while the extension collar is being removed; this prevents shearing of the specimen below the level of the top of the mould.

e. A device for removing the compacted specimen from the mould quickly and with little disturbance.

f. A balance or scale of 1 kg capacity and sensitive to 0.1 g.

Apparatus

18. a. A cylindrical metal mould is used, with a capacity of $1/454$ or 0.002205 ± 0.000020 cu ft (62.43 ± 0.57 cm³), an internal diameter of 1.313 ± 0.005 in. (33.35 ± 0.13 mm) and a height of 2.816 ± 0.005 in. (71.53 ± 0.13 mm). The mould should have a detachable collar about 1.5 in. (38 mm) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired heights and volumes. The mould and collar assembly should be constructed so that it can be fastened firmly to a detachable base plate as in Fig 4.

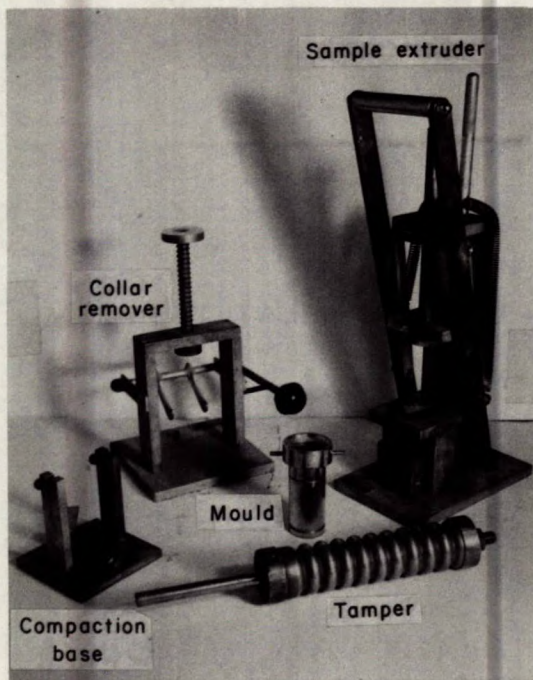


Fig 4 - Harvard miniature compaction apparatus.

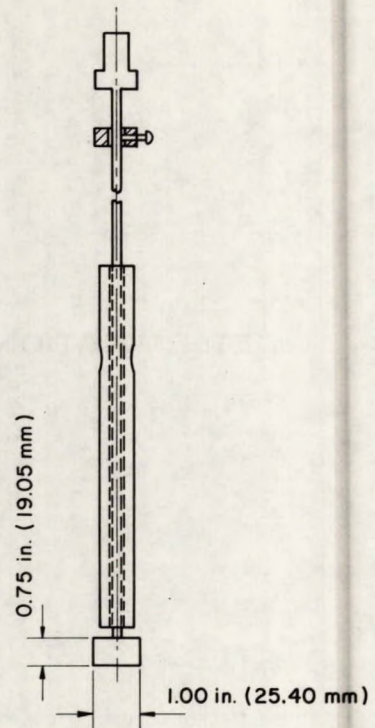


Fig 5 - Rammer.

- g. A thermostatically controlled drying oven capable of maintaining a temperature of $110^{\circ} \pm 5^{\circ}\text{C}$ for drying moisture samples.

PREPARATION OF THE TEST SPECIMEN

19. a. About 3 to 4 lb (1400 to 1800 g) of soil taken from a portion of the material passing the No. 4 (4.76 mm) sieve is air-dried to a slightly damp condition. It is mixed thoroughly to break up the lumps and insure a homogeneous mixture. The sample is then divided into six to eight portions so that each portion contains slightly more than enough material for one test. Calculated amounts of water are added to each portion so that the various moisture contents of the group will include the expected optimum content. After thorough mixing, each portion is placed in a small container with a tight fitting cover and stored overnight or until ready for testing.

b. For soils that mix readily with water and have

little or no cohesion, it is acceptable to add water and mix the specimen immediately prior to testing. It is important that a compacted specimen not be remixed and used again.

- c. Soils like heavy clays which are difficult to combine with water homogeneously may be passed through a No. 10 (2.00 mm) sieve before adding water. Water is added to the coarse fraction first before combining with the fine portion.

PROCEDURES

20. a. Method A. With the mould and collar clamped to the base, place the desired amount of loose soil in the mould. Five layers are required to produce homogeneous test specimens. For five layers, two slightly heaping teaspoonfuls of soil will be required for each layer. Level the surface by pressing lightly with a wooden plunger.
- b. Insert the tamper in the mould until it is in contact with the surface of the soil, and press down firmly until the spring starts to

sample extruder, and place in a suitable container for drying in the oven and determining moisture content. If the specimen is also to be tested in compression, it may either be dried after that test, or the excess material remaining after moulding may be used to determine the moisture content.

- g. Compact additional specimens at moisture contents both greater and less than the estimated optimum moisture content.

21. Method B. Follow the same procedure as described for Method A in paragraph 20, except that each layer should be compacted by 8 uniformly distributed blows from the rammer by dropping it freely from a height of 6.00 ± 0.05 in. (152 ± 1 mm) striking the circular base in contact with the soil.

CALCULATIONS

22. a. Calculate the moisture content and dry unit weight of the soil as compacted for each trial, as follows:

$$w = \frac{A - B}{B - C} \times 100$$

$$\text{and } \gamma_d = \frac{\gamma_m}{w + 100} \times 100$$

where, w = percentage of moisture in the specimen,

A = weight of container and wet soil,

B = weight of container and dried soil,

C = weight of container,

γ_d = dry unit weight,

γ_m = wet unit weight.

- b. Plot the dry unit weights or densities of the soil as ordinates and the corresponding moisture contents as abscissae. Draw a smooth curve which best fits the plotted points.
- c. The moisture content corresponding to the peak of the drawn curve represents the optimum

moisture content of the soil under the compaction method selected.

- d. The dry unit weight of the soil at optimum moisture content is the maximum density under the above compaction.
- compress. Release the force and shift the tamper to a new position. Each of the first four tamps should be applied in separate quadrants and adjacent to the mould. The fifth should be in the centre, making one complete coverage. Repeat this cycle until 15 tamps have been applied at a rate of about 10 per 15 sec.
- e. Add the next layer and repeat the procedure until the required number of compacted layers has been placed. The top layer should not extend more than $1/4$ in. (6 mm) into the extension collar.
- d. Transfer the mould assembly to the collar remover and carefully remove the extension collar. Carefully trim away the excess soil from the top. Next remove the mould from the base and trim its bottom.
- e. Weigh the mould containing the compacted soil to the nearest 0.1 g. and subtract the tare weight of the empty mould, to give a weight in grams numerically equal to the wet weight of the compacted soil in pounds per cubic foot, γ_m .
- f. Remove the specimen from the mould with the

REPORTING OF RESULTS

23. The report should include the following:

- a. the method used (A or B),
- b. the compactive effort (number of layers, number of tamps or blows per layer and tamping force if Method A is used),
- c. the optimum moisture content,
- d. the maximum density,
- e. a visual description of the soil.

TRIAXIAL COMPRESSION TEST WITH PORE PRESSURE MEASUREMENT

SCOPE

24. a. The triaxial compression test is used to determine the shear resistance and deformation characteristics of soils and rocks under controlled drainage conditions. In this test, a cylindrical specimen is placed in a pressure chamber, subjected to a constant confining pressure, and loaded axially to failure. The specimen is covered by a rubber membrane. Connections at the ends of the specimens permit controlled drainage of pore water to or from the specimen.

- b. The triaxial test can be performed in three different ways, depending on the drainage. The unconsolidated-undrained test (UU test) does not permit any drainage during the application of the confining pressure or during the axial loading. The consolidated-undrained test (CU test) allows drainage during the application of the confining pressure, but not during the axial loading. The consolidated-drained test (CD test) permits drainage during either stage.
- c. A detailed procedure for performing the UU test is given in the ASTM Designation: D 2850-70 (8). There are no standard methods as yet for the other two tests.

APPARATUS

25. a. A suitable compression testing machine, such as shown in Fig 6, for application of axial

load to the specimen at a constant stress rate.

- b. A device to measure the applied load with 1% accuracy, such as calibrated proving ring with a dial gauge or transducer load cell.
- c. A suitable device to measure axial deformation, such as a dial gauge or a differential transformer.
- d. Triaxial compression chamber, a cylindrical cell in which the test specimen, wrapped in a thin rubber sleeve and placed between two discs, is enclosed as shown in Fig 7. The cell consists of a head plate and a base plate separated by a transparent plastic cylinder. For testing of rocks under higher pressures the cell is made of metal. The base plate has an inlet through which the pressure liquid is supplied to the chamber, and two inlets in the specimen base and cap to permit saturation or drainage of the specimen when required. The head plate has a vent valve for removing air from the chamber. The cylinder is held tightly against rubber gaskets by bolts or tie rods connecting the head plate and base plate. The dimensions of the cell depend on the size of specimens to be tested. The inner space of the chamber can be pressurized by a liquid which subjects the specimen to a constant lateral pressure.
- e. Specimen caps and bases with discs of the same diameter as the specimen. The discs are either

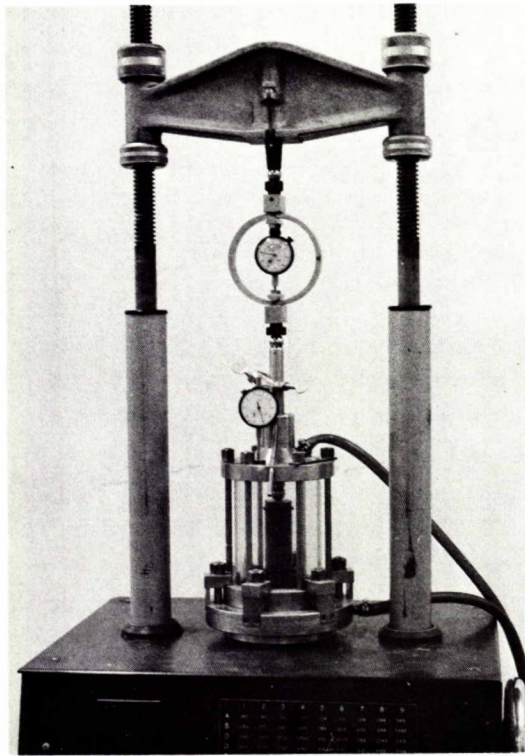


Fig 6 - Testing machine with the triaxial cell for soil testing (Elliot Lake Laboratory, CANMET).

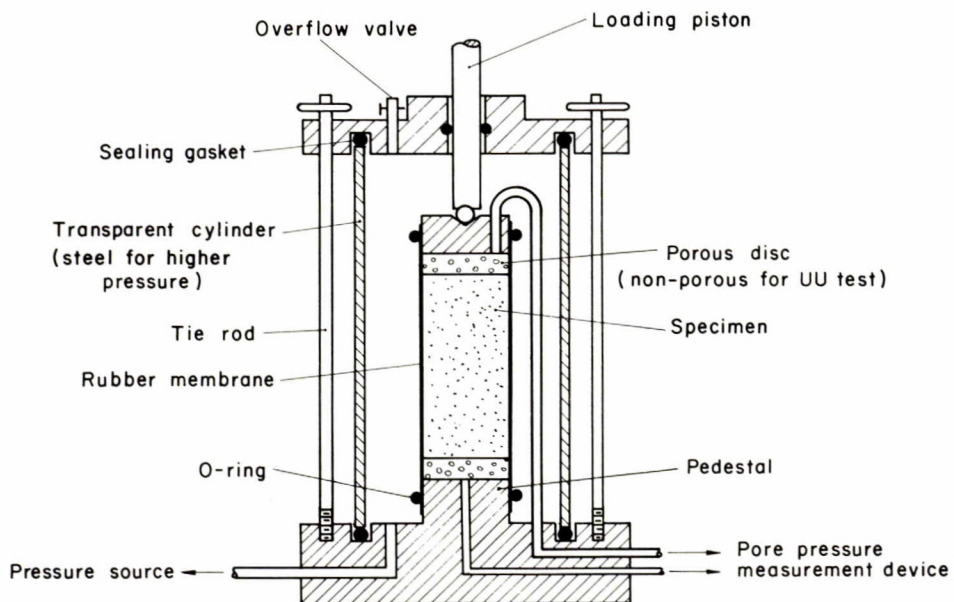


Fig 7 - Schematic cross-section of a triaxial cell with pore pressure measurement.

of impermeable material (for the UU test) or of porous material (for the CU and CD tests).

- f. Rubber membranes, to encase the specimen; these should provide protection against leakage but a minimum restraint to the specimen. The thickness of the rubber should not exceed 0.010 in. (0.25 mm).

PREPARATION OF THE TEST SPECIMEN

26. a. The minimum size of a specimen is usually determined by the maximum particle size present in the soil, and in any specimen this should not be greater than one-sixth of the diameter. Triaxial specimens between 1.4 and 4 in. (35.6 and 101.6 mm) are most commonly used; sizes up to 15 in. (381 mm) are however possible. The height of the specimen should not be less than 2 times the initial diameter.

- b. Equipment for sample preparation is different for cohesive and cohesionless soils, and for rocks. For cohesive soils a specimen trimming frame is recommended which holds the soil sample in a vertical position between two circular plates. The size of the plates corresponds to the diameter of the final specimen. Knives or wire saws are used to trim the sample to its final diameter. The length is trimmed in a mitre box or cradle. For cohesionless soils, a forming jacket is required, consisting of a split mould enclosing a rubber membrane.
- c. Guidance for sample and specimen handling and storage, and for specimen preparation, is given in Supplement 3-5.
- d. A complete investigation involves testing of several specimens at different confining pressures. At least three specimens should be tested.

PROCEDURES

- 27. a. The specimen, with the lower porous disc underneath, is centred on the pedestal of the base.
- b. After the upper porous disc and the loading cap are placed on top of the specimen, the rubber membrane is installed with the aid of a

membrane stretcher, and then the O-ring seals are placed around the membrane at both ends.

- c. After the upper pore pressure line within the chamber is connected, the triaxial chamber is assembled.
- d. The triaxial cell is centred on the loading platform of the compressive machine; the deformation measuring device is positioned; the lines of the pore pressure measuring system and of the lateral pressure system are connected; while the overflow valve is kept open, the cell is filled with the pressure fluid.
- e. The loading piston is brought into contact with the loading cap and after closing the overflow valve the lateral fluid pressure is slowly raised to the predetermined test level, while the contact between the piston and the cap is maintained by applying the required axial load. The axial strain indicator is set to zero.
- f. The loading rate of the compression machine is set and loading is started. In the case of a UU test, an axial strain rate of 1% per minute is applied for plastic materials and 0.3% per minute for non-plastic brittle materials. Considerably slower strain rates are required for the CU and CD test (9).
- g. Readings of vertical load are recorded at selected increments of deformation, usually at 0.5% of strain, until the load becomes constant, or falls, or the axial strain reaches 20%.
- h. The chamber pressure is released, the chamber drained, and the triaxial cell disassembled.
- i. The water content of the failed specimen is determined by the method described in Supplement 3-1.

Pore Water Pressure Measurement

- 28. a. The pore water pressure should be known at any stage of the test to express the results of a triaxial test in terms of effective stresses.
- b. It should be measured under conditions in which there is no change in volume of the specimen. The no volume change, or no flow condition can be maintained by the use of a null indicator, essentially a U-shaped tube partly filled with

mercury as shown in Fig 8. The null indicator is located between the specimen and a pressure control and pressure measurement system. The whole system is filled with deaerated water.

- c. Any change in pore water pressure within the specimen tends to change the mercury level in the indicator. This is prevented by changing the pressure in the other half of the system by means of the control cylinder. The balancing pressure at unaltered mercury level, as recorded by the pressure gauge, is then equal to the pore water pressure in the specimen.

29. The pore water pressure measurement system shown in Fig 8 can be replaced by a suitable pressure transducer which should have a very low volume change characteristic.

CALCULATIONS

30. a. The axial strain is computed from the following equation:

$$\epsilon = \frac{\Delta L}{L_0}$$

where, ΔL = the axial deformation of the specimen,
 L_0 = the initial length of the specimen.

- b. The average cross-sectional area of the specimen for a given strain level is:

$$A = A_0 \frac{1 - \Delta V/V_0}{1 - \Delta L/L_0}$$

where, A_0 = the initial cross-sectional area of the specimen,

$\Delta V/V_0$ = volumetric strain (in the cases of UU and CU tests, it equals zero).

ΔV = volume change of the specimen,

V_0 = initial volume of the specimen.

- c. The principal stress-difference for a given strain is calculated by the following equation:

$$\sigma_1 - \sigma_3 = \frac{P}{A}$$

where, P = the net applied load.

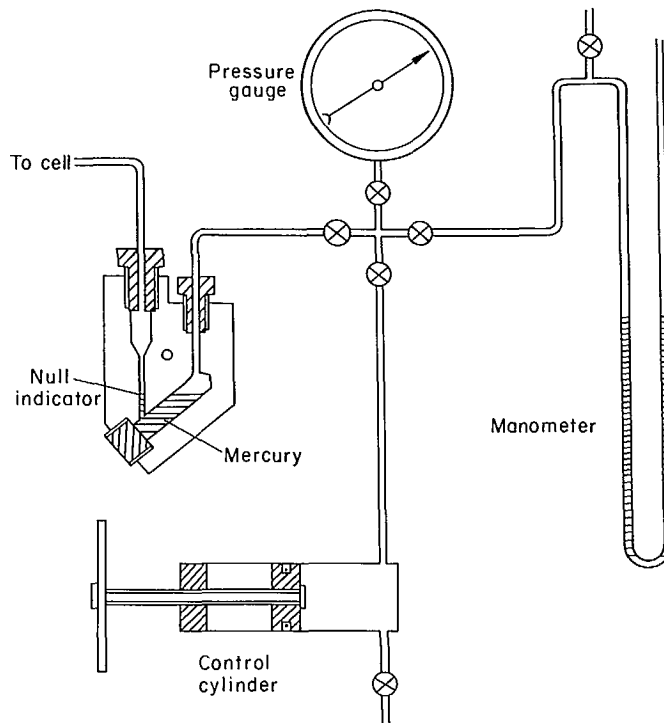


Fig 8 - Pore water pressure measuring system.

REPORTING OF RESULTS

31. a. The test results are presented graphically, eg by stress-strain diagram and Mohr's circle diagram. When the pore pressure in the cases of UU and CU tests is measured, the stress-strain diagram is combined with the pore pressure vs axial strain plot. In the case of drained tests, a plot of volume change vs axial strain is added to the stress-strain plot as shown in Fig 10(a).

b. The resulting graphs are interpreted. The interpretation of test results is determined by the conditions which are dependent upon the test type.

Unconsolidated-Undrained Test

32. a. This test is usually used to test the undisturbed specimens of fine grained and cohesive soils such as clay, silt, and peat, for determining the in situ strength needed for the stability analysis in terms of total stresses ie, $\phi = 0$ analysis.

b. If such a test is performed on a saturated soil, the $\sigma_1 - \sigma_3$ stress difference is independent of the applied σ_3 confining pressure. Fig 9 shows the corresponding Mohr's circle diagram. It follows that $\phi = 0$ and $c_u = (\sigma_1 - \sigma_3)/2$.

c. If the pore pressure is measured during the test, the effective stresses can be obtained as shown by the dashed lines in Fig 9. In the case of saturated soils however, even a series of UU tests furnishes only one effective stress circle; the shape of the failure envelope, in terms of effective stresses, cannot therefore be determined. Consequently, consolidated-undrained or consolidated-drained tests should be used for this purpose.

Consolidated-Undrained Test

33. a. The consolidated-undrained test provides sufficient data to establish the undrained strength of a clay as a function of the void ratio, or of the corresponding consolidation pressure p .

b. Since each consolidation pressure results in a corresponding apparent cohesion c_u , the results of a series of CU tests can be represented by plotting the obtained values of c_u (with $\phi_u = 0$) against the corresponding consolidation pressure, p , as shown in Fig 10(b).

c. For a normally consolidated clay, the relationship between c_u and p is linear, and passes through the origin. For an over-consolidated clay, in the region of p values lower than the over-consolidation pressure, p_c , the relation-

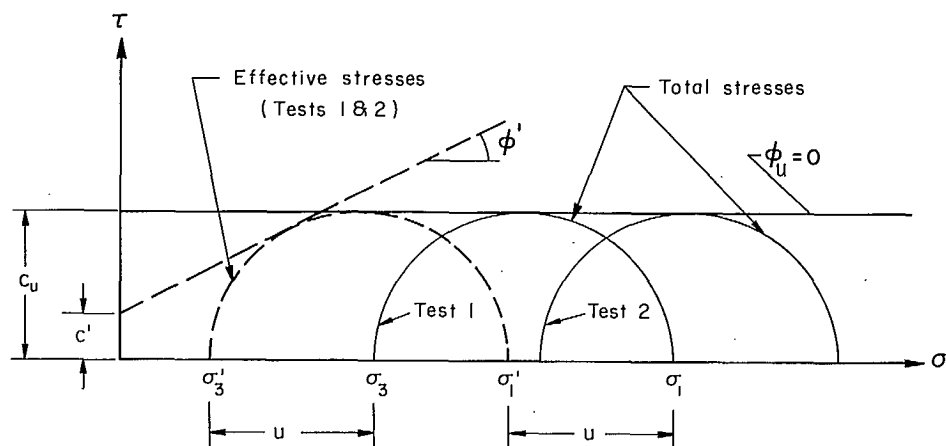


Fig 9 - Mohr's stress circles for undrained tests on saturated cohesive soil.

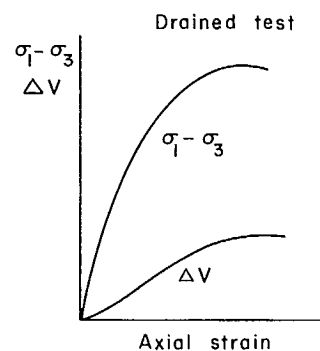
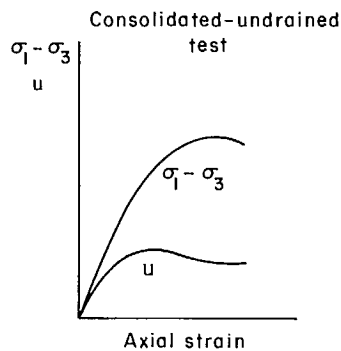
ship between c_u and p is non-linear.

Strength in Terms of Effective Stresses

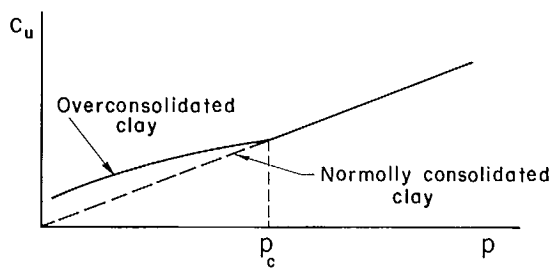
34. a. The strength of a soil in terms of effective stresses can be determined either by the consolidated-undrained triaxial tests with pore pressure measurement or by the drained triaxial test.

b. To determine the function between the angle of internal friction and the density and normal pressure for sands, the drained triaxial test is the most appropriate method.

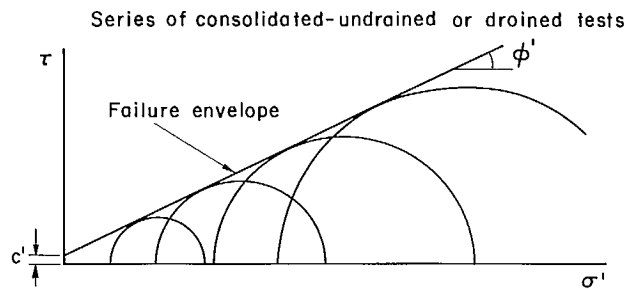
c. If the pore water pressure at failure in the CU tests is known, then the effective principal stresses, σ_1' and σ_3' , can be calculated ie, $\sigma_1' = \sigma_1 - u$, $\sigma_3' = \sigma_3 - u$, and the corresponding Mohr's circle can be drawn. Adequate numbers of such tests, each performed at a different value of consolidation pressure p , provide the required data to draw the failure envelope and thus to establish the shear strength parameters c' and ϕ' , shown in Fig 10(c).



(a)



(b)



(c)

Fig 10 - Results of consolidated-undrained and drained triaxial tests: (a) stress-strain diagrams from CU and CD tests; (b) undrained cohesion, c_u , as a function of consolidation pressure, p , determined in CU tests; (c) strength of saturated clay in terms of effective stress.

FIELD VANE SHEAR TEST

SCOPE

35. a. This test is used for in situ determination of the undrained strength of non-fissured, fully saturated clays.
- b. It is particularly useful in the case of soft clay, when the shear strength could be significantly altered by any sampling process.
- c. This test is not suitable for other types of soil.
- d. Details are given in ASTM Designation: D 2573-72 (10).

APPARATUS

36. a. The equipment consists of a stainless steel vane of four thin rectangular blades mounted at the end of a high tensile steel rod. The rod is enclosed by a sleeve and packed with grease.
- b. The height of the vane is equal to twice its overall diameter; recommended dimensions are given in Fig 11.

PROCEDURE

37. a. The vane and rod are pushed into the clay below the bottom of a borehole to a depth of at least three times the borehole diameter.
- b. Alternatively, in the case of soft clay, the

vane is pushed into the clay without a borehole, and the vane is protected by a suitable shoe.

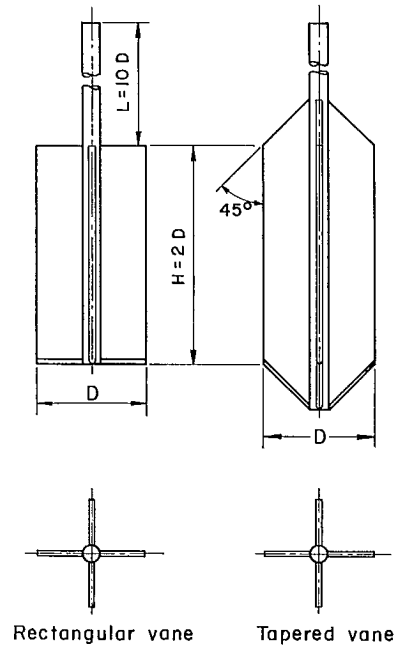
- c. Torque is gradually applied at the end of the rod until the clay fails in shear due to the rotation of the vane.
- d. The rate of rotation should be within the range of 6° to 12° per minute.
- e. The procedure is repeated at intervals over the depth of interest.
- f. If the vane is rapidly rotated through several revolutions, after initial failure, the clay becomes remoulded. Shear strength corresponding to the remoulded condition could then be determined if required.

CALCULATIONS

38. The shear strength is calculated from the following equation:

$$\tau_f = \frac{6T}{\pi D^3 (1 + 3H/D)}$$

- where, T = torque at failure,
 D = overall diameter of the vane,
 H = height of the vane.



Recommended dimensions of field vanes

Casing size	Diameter in.(mm)	Height in.(mm)	Thickness of blade in.(mm)	Diameter of vane rod in.(mm)
AX	1 1/2 (38.1)	3 (76.2)	1/16 (1.6)	1/2 (12.7)
BX	2 (50.8)	4 (101.6)	1/16 (1.6)	1/2 (12.7)
NX	2 1/2 (63.5)	5 (127.0)	1/8 (3.2)	1/2 (12.7)
4 in.(101.6mm)	3 5/8 (92.1)	7 1/4 (184.1)	1/8 (3.2)	1/2 (12.7)

Fig 11 - Geometry and recommended dimensions of field vanes.

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