PIT SLOPE MANUAL

supplement 3-3

IN SITU FIELD TESTS

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PIT SLOPE PROJECT

of the

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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 in situ tests for deformation and strength properties of slope materials and for classification and characterization of slope materials. Deformation modulus is determined by dilatometer tests in a borehole. In situ direct shear strength is determined by isolating a suitable specimen through sawing and drilling, and using in situ jacks to provide normal and horizontal forces. In situ density is determined by measuring the volume of an excavated hole, and weighing the excavated material. The in situ density of rock can also be determined from production blast holes by weighing the drill cuttings.

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M. Gyenge and G. Herget were responsible for this chapter. Address enquiries to them at: 555 Booth Street, Ottawa, K1A 0G1, Canada.

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FIGURES

INTRODUCTION

1. Supplement 3-3 covers the in situ field testing methods. One type of testing deals with the in situ deformation and strength properties of the slope materials. The others are required for classification and characterization of the slope materials.

2. The large scale in situ shear tests and deformability tests are usually the best methods to obtain highly reliable design data, provided that an adequate number of tests are performed. However, because of their high cost, they are used only in special cases when justified because of stability requirements.

3. Due to the great variation in prevailing conditions, requirements and circumstances from one mining site to another, the intention of this supplement is to provide only useful guidance on the testing procedures, without attempting to set rigorous standards.

4. The description of the in situ direct shear test is based mainly on the testing method suggested by the Commission on Standardization of Laboratory and Field Tests of the International Society for Rock Mechanics. Proper reference is given at the end of the supplement together with a list of selected related publications.

5. A majority of the testing methods included within the field classification and characterization tests have been standardized by the American Society of Testing and Materials. The appropriate standards are not reproduced herein, so consequently the reader should consult the standard methods for more details.

6. There are other in situ properties which can be used for characterization purpose, such as electrical resistivity and seismic properties. Descriptions of the related testing procedures are detailed in Chapter 2, "Structural Geology", of this manual because these procedures are conducted within the structural geology investigation phase and are used in establishing the structural domains of the rock mass.

DETERMINATION OF DEFORMATION MODULUS BY DILATOMETER TEST

SCOPE

7. a. The purpose of this test is to establish the deformation modulus of a soil or rock mass in a borehole.

b. In addition, the test may also be used to assess the strength of the tested material.

c. The principal feature of the test is an expandable probe which is subjected to a constant pressure, and the resulting volumetric change is recorded. At the same location in the borehole pressures are increased in increments. The relationship between increasing pressure and volumetric change provides a basis for the derivation of deformation modulus and shear strength.

APPARATUS

8. a. The pressuremeter test system consists of two separate units, an expandable probe and a pressure volumeter (Fig 1). The probe consists of a shaft with a spring-loaded lower section, surrounded by two rubber membranes of which the inner forms the measuring cell. The outer membrane protects the inner as a guard cell and expands radially but not axially.

b. The guard cell is activated by gas pressure; the measuring cell is charged with water kept at a pressure slightly higher than in the guard cell to ensure contact with the borehole wall.

c. The probe is connected to the pressure volumeter by coaxial tubing, the inner tube carrying the water phase. The coaxial arrangement prevents undesirable expansion of the water line on the application of pressure.

d. The pressure volumeter consists of a water supply tank, burette, a system of valves for control of pressure of the two phases, and a tank of compressed CO_2 as a source of pressure.

PROCEDURE

9. a. For the test, the pressure probe can be placed in the hole in two different ways. One method is to drill a hole with a diameter only slightly larger than that of the probe to the final depth of investigation. The pressure meter tests are then performed at the desired elevations without withdrawing the probe. This method is faster, but requires accurate drilling. It is also difficult to use in granular soils, or in highly disintegrated rocks.

b. With the second method, a borehole of a diameter usually one inch larger than that of the pressure probe is drilled to a point short of the test elevation by one half of the probe's length. The larger diameter hole can be cased if necessary. A test hole with a diameter and length fitting the probe is then drilled from the bottom of the larger hole. This method, though more time consuming, can be used in almost all rock or soil types and does

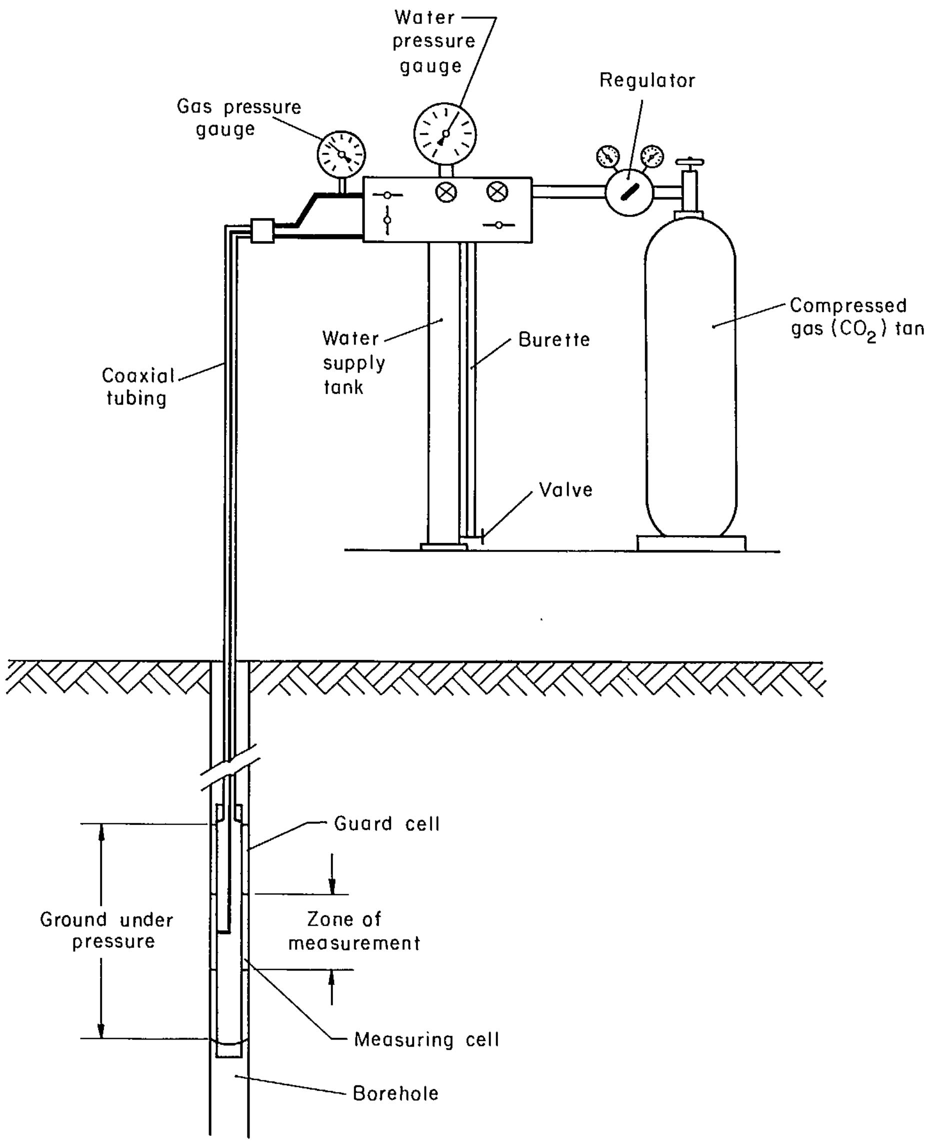

Fig 1 - Schematic layout of a dilatometer test system.

not involve special requirements in drilling technique.

c. The entire test at a given test location is performed by increasing the pressure in controlled steps, and measuring the volume expansion for each pressure increment.

CALCULATIONS

10. a. The volume expansion at a given pressure is time-dependent. A typical volume-time curve is shown in Fig 2.

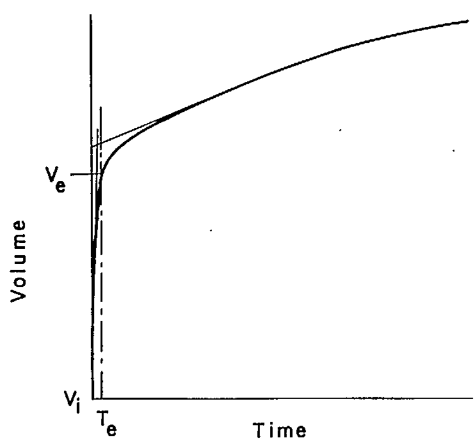

Fig 2 - Typical volume-time curve for dilatometer test.

b. From this curve the elastic time interval, T_e, and the elastic volume change, V_e, are determined.

c. Once the value of V_e is found for each pressure increment, a complete relationship between volume and pressure can be constructed. A typical volume-pressure curve is presented in Fig 3.

d. The curve shows three distinct phases. The first, a lead-in phase, restores the lateral stresses existing in the ground before drilling, and recompacts the ground disturbed by drilling.

e. The second is a pseudo-elastic phase and is important in evaluating the deformation properties of surrounding rock or soil. The deformation modulus is calculated from the following equation (1):

$$D = \frac{2V_o(1+\mu)\Delta P}{\Delta\ V}$$

where, V_o denotes the volume of the measuring cell at the beginning of the pseudo-elastic phase,

μ denotes Poisson's ratio, which has to be estimated,

$\frac{\Delta P}{\Delta V}$ is the slope of the curve in the pseudo-elastic phase, in which ΔV is the volume change corrected by the compliance effect of the whole system. The compliance effect is directly measurable by performing a test inside a steel casing.

f. The third part of the volume-pressure curve, a plastic phase, may be used to assess the strength of the tested material. Although no generally accepted theoretical approach exists at present to evaluate this part of the test in any type of ground, there are works which indicate solutions for some specified soil and rock types (1, 2, 3, 4).

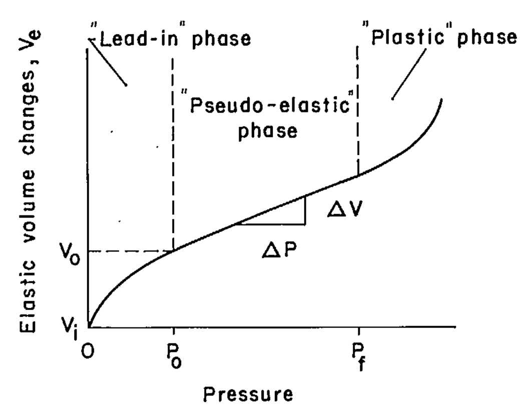

Fig 3 - Typical volume-pressure curve for dilatometer test.

DETERMINATION OF IN SITU DIRECT SHEAR STRENGTH

SCOPE

11. a. The purpose of this test is to measure the in situ peak and residual direct shear strengths as functions of stress normal to the sheared plane. The test is usually employed when investigating dam foundations, however, it can also be used in connection with slope stability analyses.

b. The inclination of the test block and system of applied loads is usually selected so that the sheared plane coincides with a plane of weakness in the rock, eg, a joint, bedding plane schistosity or cleavage, or with an interface between soil and rock. Intact weak rock can also be tested.

c. A shear strength determination should preferably consist of five tests at least on the same test horizon, with each specimen tested at some constant normal stress which differs among the specimens.

d. The porewater pressure conditions and the possibility of progressive failure must be assessed in applying results of the test to the design case, as these may differ from the test conditions.

e. All procedures for determining the in situ direct shear strength are based on a suggested method (5).

APPARATUS

12. Equipment for cutting and encapsulating the test block, rock saws, drills, hammer and chisels, formwork of appropriate dimensions and rigidity, expanded polystyrine sheeting or weak filler, and materials for reinforced concrete encapsulation.

13. Equipment for applying the normal load as in Fig 4, includes:

a. Flat jacks, hydraulic rams, or a dead load sufficient for the required normal loads.

b. A hydraulic pump which should be capable of maintaining a normal load within 2% of a selected value.

c. A reaction system transfers normal loads uniformly to the test block, which may include rollers or a similar low-friction device, to ensure that at any given normal load the resistance to shear displacement is less than 1% of the maximum shear force applied. Rock anchors, wire ties and turnbuckles are usually required to install and to secure the equipment.

14. Equipment for applying the shear force as in Fig 4 includes:

a. One or more hydraulic rams or flat jacks of adequate total capacity, and with at least 3 in. (75 mm) travel.

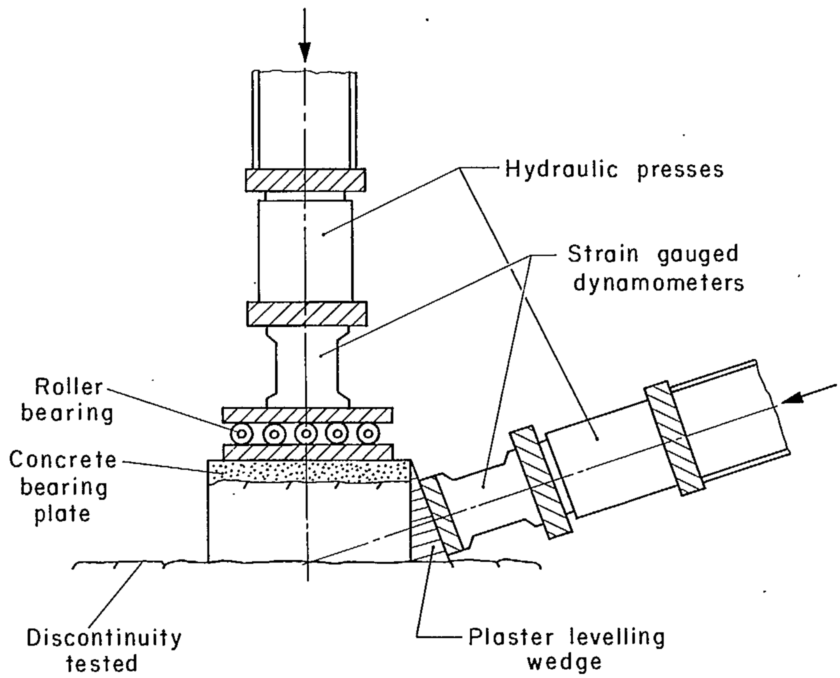

Fig 4 - Direct shear test set-up with an exposed block.

b. A hydraulic pump to supply the shear force system.

c. A reaction system to transmit the shear force to the test block. The shear force should be distributed uniformly along one face of the specimen, and its resultant should pass through the centre of the base of the shear plane, with an angular tolerance of ± 5°.

15. Equipment for measuring the applied forces includes:

a. One system for measuring normal force and another for measuring applied shearing force with an accuracy within ± 2% of the maximum; load cells, dynamometers, or flat jack devices may be used.

16. Equipment for measuring shear and normal displacement:

a. Displacements on the specimen block, in encapsulating material or in the encasement frame, should be measured with suitable devices such as micrometer dial gauges or electric transducers.

b. The shear displacement measuring system should have a travel of at least 3 in. (75 mm) and an accuracy within ± 0.05 in. (0.1 mm); the normal measuring system should have a travel of at least 1 in. (25 mm) and an accuracy ± 0.002 in. (0.05 mm). The beams, anchors and clamps used in the measuring system should be sufficiently rigid for these requirements.

c. The number of gauges needed for measuring displacement is primarily dependent on the test block length, measured parallel to the direction of shear. To obtain a complete description of movement along a discontinuity at least four gauges are needed to measure the horizontal displacement, ie one in each corner, and at least two gauges to measure horizontal displacement ie, one at each side. The gauges should be placed as close as possible to the shear plane to avoid effects of compressibility in the block material.

PREPARATION OF THE TEST SPECIMEN

17. a. A field shear test is carried out on an intact block of rock isolated from the surrounding mass by excavation or drilling. Drilling vibrations should be kept to a minimum to prevent loss of strength in the discontinuity surface. The excavation should be large enough to accommodate loading and measuring devices.

b. To avoid excessive disturbance during excavation or drilling, hand mining techniques should be used close to the proposed test surface. This is particularly important when preparing the entire testing block. To reduce discontinuity disturbance during specimen preparation, a small load can be placed on the proposed specimen, acting normally to the discontinuity.

c. The test block above the discontinuity should be free of joints and other weak zones to obtain an effective transmission of the normal and shear loads onto the plane being tested. Selection of the test area is governed by the capacities of available loading systems. While an area of one square foot (0.1 m^2) can be taken as a minimum, larger scales would provide more representative results.

18. The arrangement of the insitu direct shear test depends on the suitability of the test site (6, 7, 8, 9, 10). It can be arranged:

a. in an open trench, if the selected discontinuity is accessible from the surface as in Fig 5;

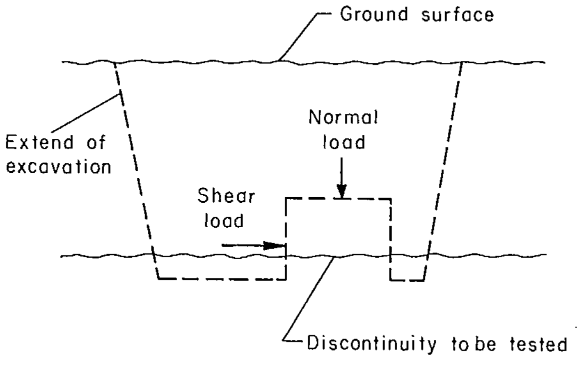

Fig 5 - Schematic layout of an in situ shear test within a trench.

b. in an adit specially excavated to reach the desired discontinuity;

c. in any other tunnel or drift;

d. at the bottom of a large drill hole, as shown in Fig 6.

e. in a 12 7/8 in. (32.7 cm) drill hole with the arrangement shown in Fig 8.

19. If the test block is competent and the possibility of disintegration during the test is therefore remote, the exposed block can be tested without any encasement. The normal and shear loads are transmitted to the rock by bearing plates or beams in the ways shown in Fig 4, 7, and 8.

20. The blocks may be reinforced during the test, if required. Test blocks are often encased in steel frames with concrete, mortar, or grout placed between the frame and sides of the test block. Sand, concrete, or mortar can be placed on the upper surface beneath the cover or loading plate. A typical arrangement using a steel frame and grout is shown in Fig 9. The steel frame can be replaced by a reinforced concrete frame.

PROCEDURE

21. a. The reaction pads, anchors, etc, used to carry the thrust from normal and shear load systems to adjacent sound rock, are carefully positioned and aligned. All displacement devices are checked for rigidity, adequate travel, and freedom of movement.

b. A seating load set, equivalent to 1% of the estimated uniaxial strength of the rock material, is applied on both the normal and shear load systems. The displacements noted are recorded as zero readings.

c. The normal load is then raised to the full value predetermined for the test run. The resultant normal displacements, which represent consolidation of the test block, are recorded as a function of time, while maintaining the normal load at a constant value.

d. The consolidation stage is considered complete when the rate of change of normal displacement recorded at each of the displacement measuring devices is less than 0.002 in (0.05 mm) in 10

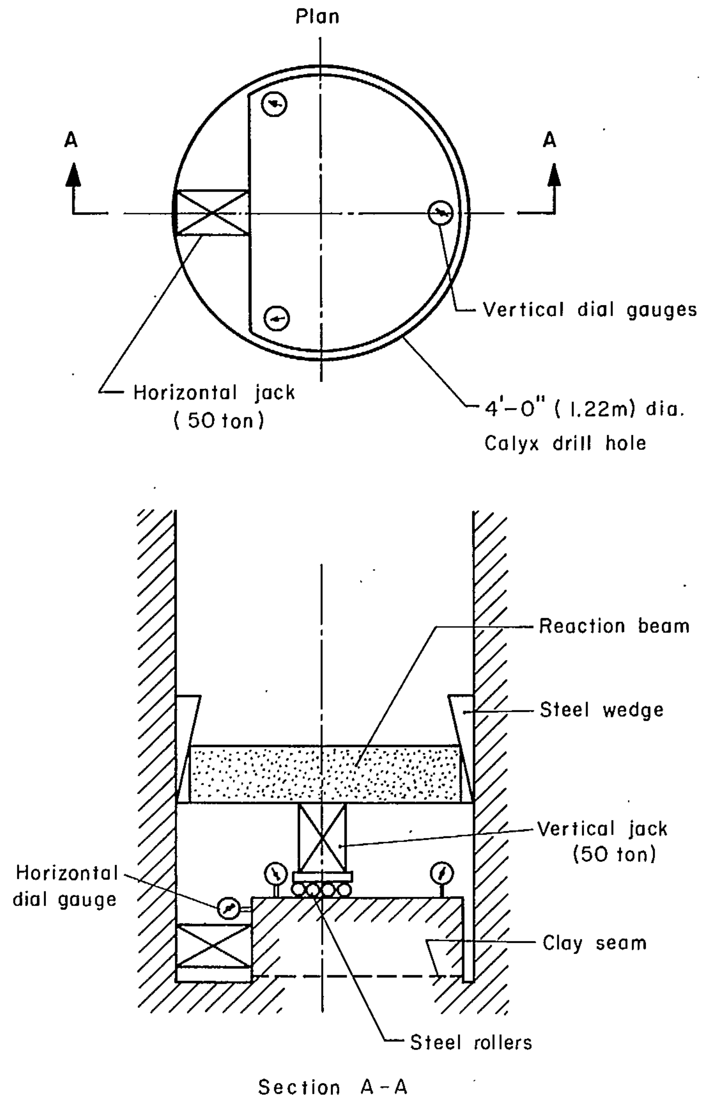

Fig 6 - Schematic layout of an in situ shear test at the bottom of a large drill hole.

minutes.

e. Shear loading is then applied, either in increments or continuously in such a way as to control the rate of shear displacement.

f. The direction of the shear load should preferably be parallel to the discontinuity plane being tested. The applied normal force should otherwise be reduced after each increase in shear by an amount equal to $P_{sa} \sin \alpha$ in order to maintain the normal stress approximately constant where P_{sa} is the applied shear force and α is its obliquity to the shear plane as in Fig 4. The applied normal force may be further reduced during the test by an amount equal to $P_n \Delta_s / \ell$ to compensate for the area change, where P_n is the total normal force, Δ_s is the shear displacement, and ℓ is the dimension of the test block in the direction of shearing.

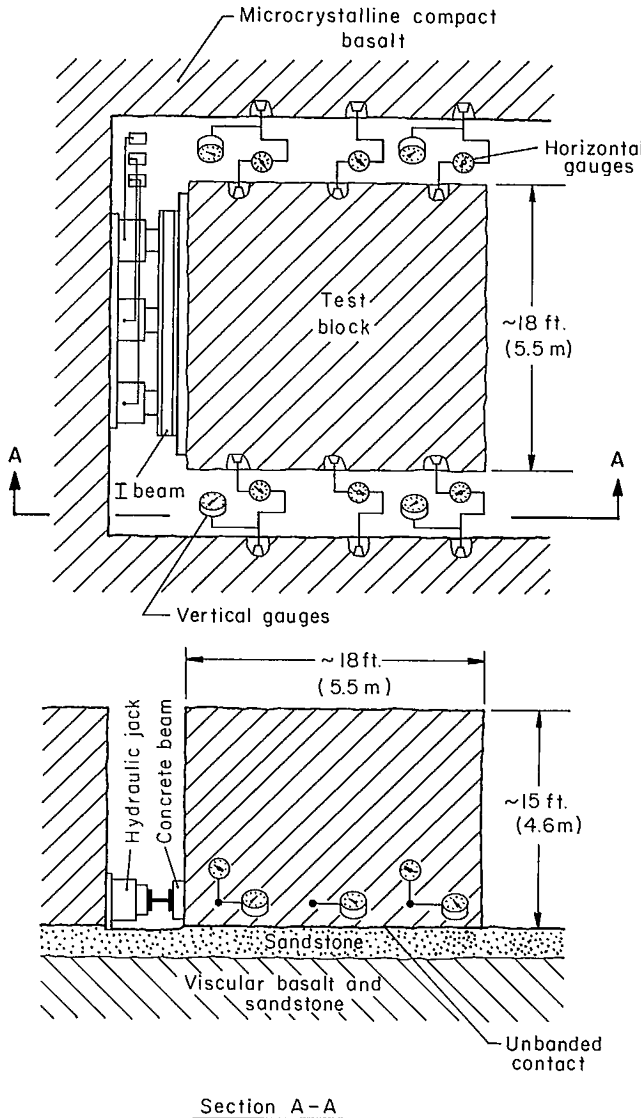

Fig 7 - Schematic arrangement of loading and displacement measuring systems.

g. Approximately 10 sets of readings should be taken before reaching peak strength. The rate of shear displacement should be less than 0.005 in./min (0.1 mm/min) in the 10 minute period before taking a set of readings. This rate may be increased up to 0.025 in./min (0.5 mm/min) between sets of readings, provided that the peak strength itself is adequately recorded.

h. After reaching the peak strength, readings should be taken at increments of 0.025 in. (0.5 mm) to 0.25 in. (5 mm) shear displacement, as required to adequately define the force-displacement curves of Fig 10. The rate of shear displacement should be between 0.001 in./min (0.02 mm/min) and 0.01 in./min (0.2 mm/min) in

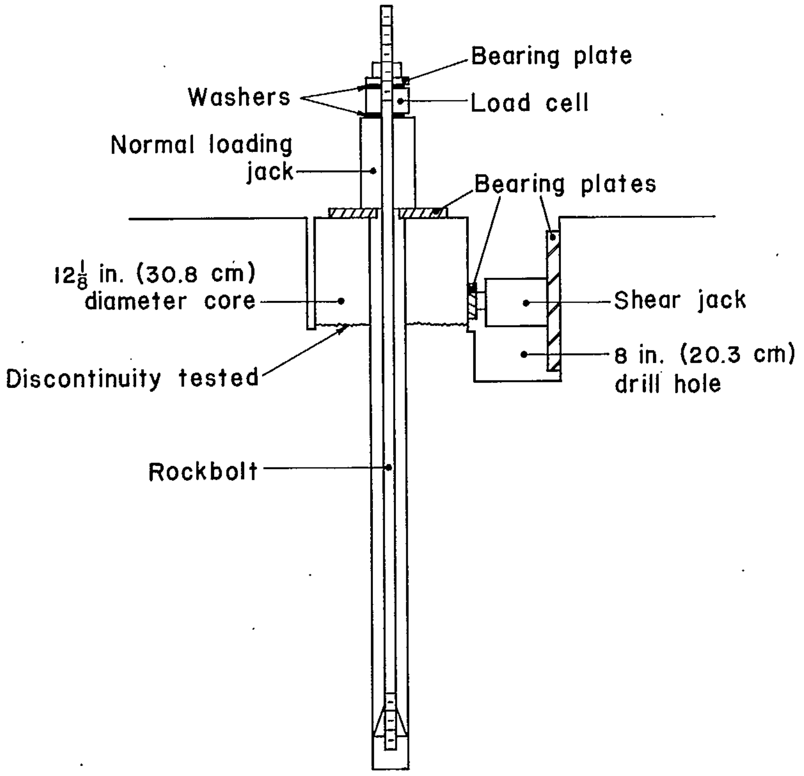

Fig 8 - Direct shear test in 12 7/8 in. (32.7 cm) diameter hole; the shear jack is located in adjoining 8 in. (20.3 cm) diameter hole.

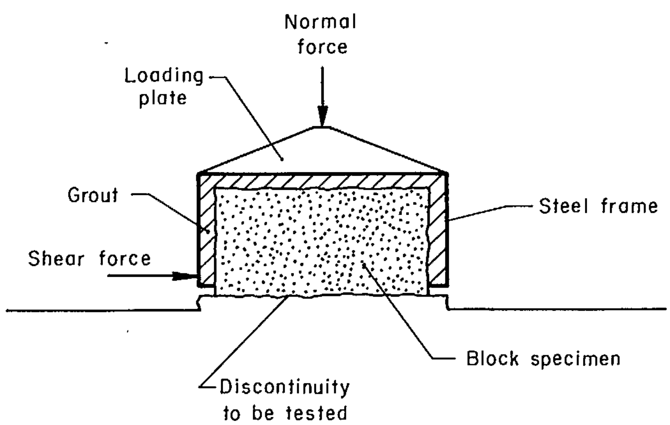

Fig 9 - Direct shear test set-up using steel frame encasement.

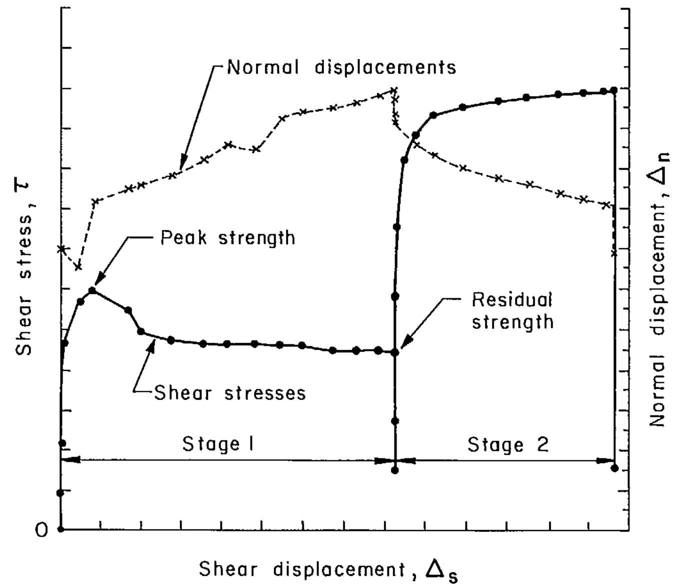

Fig 10 - Shear stress-displacement graphs.

the 10 minute period before a set of readings is taken, and may be increased to not more than 0.05 in./min (1 mm/min) between sets of readings.

i. It may be possible to establish a residual strength value when the sample is sheared at constant normal stress and at least four consecutive sets of readings show not more than 5% variation in shear stress over a shear displacement of 0.5 in. (1 cm).

j. Having established a residual strength, the normal stress may be increased and shearing continued to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress value, and shearing continued according to criteria given in steps (g) to (i) above.

k. After the test, the block should be inverted, photographed in colour and fully described in paragraph 23 below. Measurements of the area, roughness, dip and dip direction of the sheared surface are required and samples of rock, infilling and shear debris should be taken for index testing.

CALCULATIONS

22. a. Displacement readings are averaged to obtain mean shear and normal displacements.

b. Shear and normal stresses are computed as follows:

$$\text{Shear stress, } \tau = \frac{P_s}{A} = \frac{P_{sa} \cos \alpha}{A}$$

$$\text{Normal stress, } {}_{n} = \frac{P_n}{A} = \frac{P_{na} + P_{sa} \sin}{A}$$

where, P_s = total shear force,

P_n = total normal force,

P_{sa} = applied shear force,

P_{na} = applied normal force,

α = inclination of applied shear force to the shear plane,

A = area of shear surface overlap, which may be corrected for shear displacement.

c. For each test specimen, graphs of shear stress, or shear force, and normal displacement vs shear displacement are plotted as in Fig 10, annotated to show the nominal normal stress and any changesin normal stress during shearing. Values of peak and residual shear strength and the normal stresses, the shear and normal displacements at which these occur, are derived from these graphs.

d. Graphs of peak and residual shear strength vs normal stress are plotted from the combined results for all test specimens (Fig 11). Shear strength parameters ϕ_a, ϕ_r, ϕ_t, c_t are derived from these graphs.

REPORTING OF RESULTS

23. The report should include:

a. A diagram, photograph and detailed description of test equipment, and a description of methods used for specimen preparation and testing.

b. For each specimen, a complete geological description should be provided for the intact rock, sheared surface, filling and debris, preferably accompanied by relevant index test data eg, Atterberg limits, water content, and grain size distribution of filling materials.

c. Photographs of each sheared surface should be included together with diagrams giving the location, dimensions,area, dip and dip direction, and showing the directions of shearing and any peculiarities of the blocks.

d. A set of data tables, graphs and tabulated values of peak and residual shear strength vs normal stress should be given for each test block, together with derived values for the shear strength parameters indicated in Fig 11.

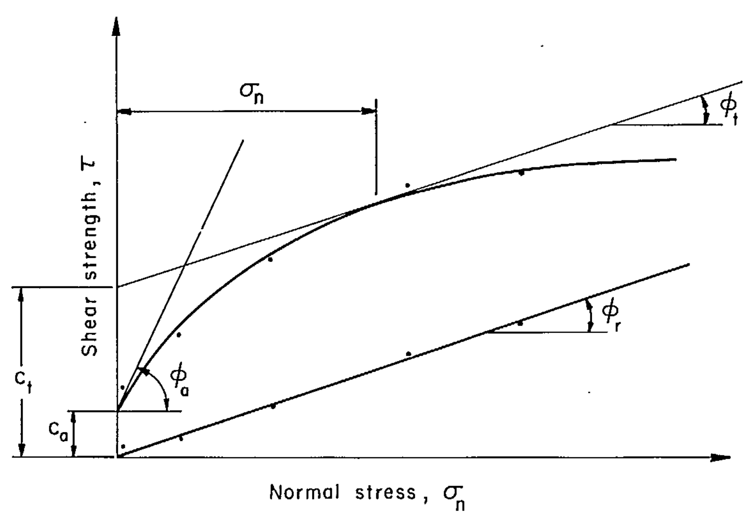

Fig 11 - Shear strength-normal stress graph.

DETERMINATION OF IN SITU DENSITY OF SOILS AND SOIL-LIKE ROCK MATERIALS

SCOPE

24. a. The purpose of these tests is to establish the in situ bulk density of soils and soil-like rock materials, such as highly disintegrated rocks.

b. Three different types of standardized testing methods are available for this purpose. The selected method should be suited to the soil type to be tested.

SAND-CONE METHOD

25. a. A detailed description of this method is given in ASTM Designation: D 1556-64 (11).

b. The method is restricted to tests in soils and soil-like rock materials containing particles not larger than 2 in. (51 mm) in diameter.

c. A schematic drawing of the apparatus to be used is shown in Fig 12.

d. The test method consists of digging a hole from surface within the material to be tested, weighing the material excavated and determining the volume of the hole.

e. The volume of the irregularly shaped hole is measured by pouring dry, clean sand into the hole from the calibrated jar through a funnel of known volume and from a constant height (Fig 12).

RUBBER-BALLOON METHOD

26. a. A detailed description of this method is given in ASTM Designation: D 2167-66 (12).

b. The method is suitable for testing compacted or firmly bonded soils. It is not suitable for very soft soil which deforms under slight pressure or in which the volume of the hole cannot be maintained at a constant value.

c. A schematic drawing of the apparatus to be used is shown in Fig 13.

d. The test method consists of digging a hole from surface within the material to be tested, weighing the material excavated and determining the volume of the hole.

e. The volume of the irregularly shaped hole is measured by a rubber balloon filled with water. The balloon, attached to a calibrated vessel, is placed first on the surface before digging and then in the hole after it is excavated. The volume reading is recorded both times. The difference between the readings gives the volume of the hole.

DRIVE-CYLINDER METHOD

27. a. A detailed description of this method is given in ASTM Designation: D 2937-71 (13).

b. The method is not suitable for testing very hard soils which cannot be penetrated easily, nor for soils of low plasticity which are not readily retained in the cylinder.

c. A schematic drawing of the equipment to be used at or near the surface is shown in Fig 14.

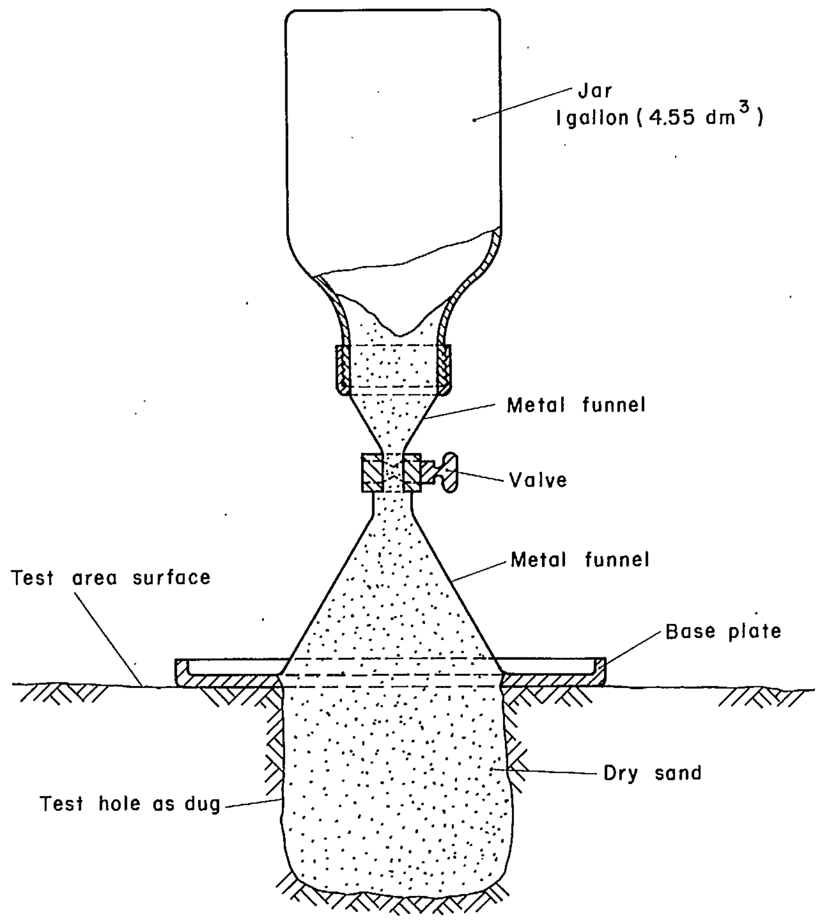

Fig 12 - Schematic drawing of the apparatus, indicating the principle of the sand-cone method.

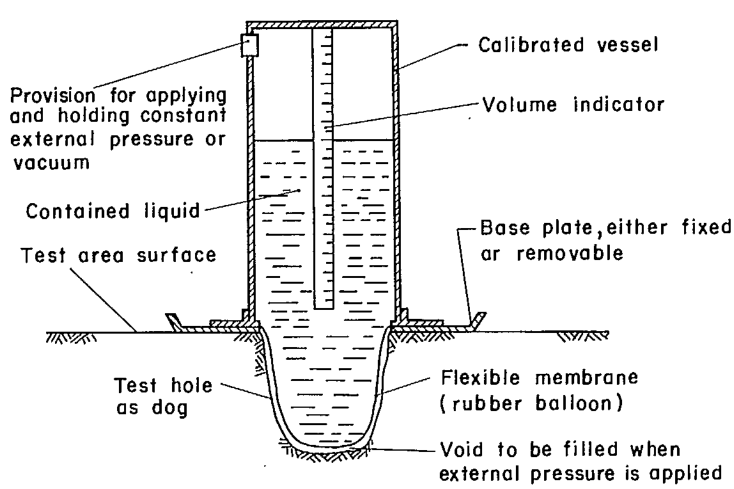

Fig 13 - Schematic drawing of the apparatus, indicating the principle of the rubber-balloon method.

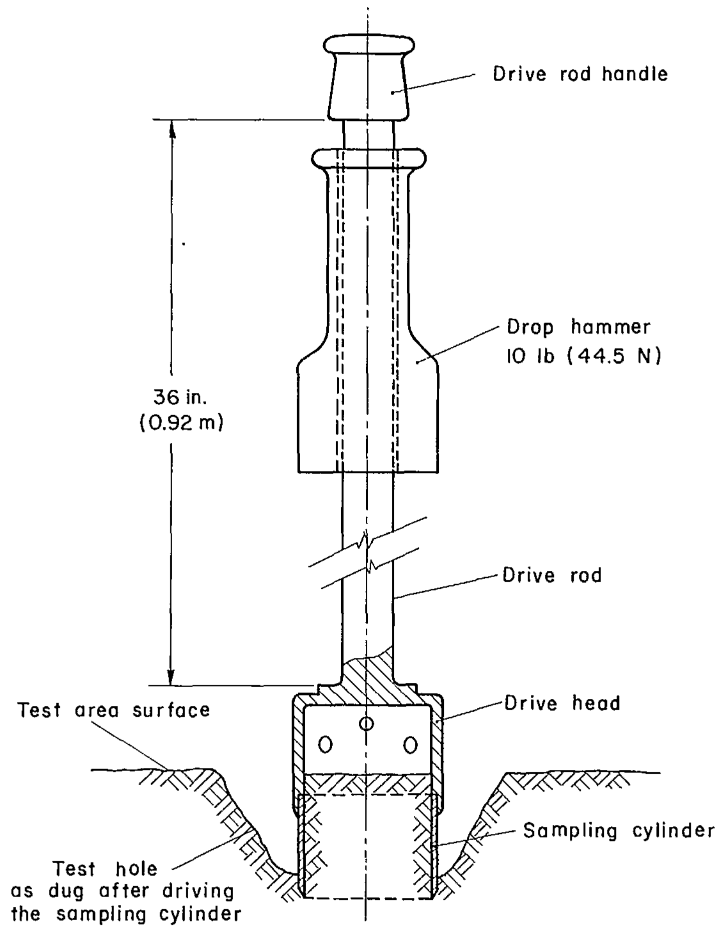

Fig 14 - Schematic drawing of the equipment, indicating the principle of the drive-cylinder method.

d. The method involves obtaining a relatively undisturbed soil sample of known volume by driving a thin-walled cylinder into the soil with a special driving head.

e. The density is then calculated from the weight and volume of the sample.

DETERMINATION OF IN SITU DENSITY OF ROCKS

SCOPE

28. The purpose of this test is to establish the in situ bulk density of rocks by using production blast holes.

APPARATUS

29. a. A suitable calliper to measure the diameter of the blast hole with an accuracy of 0.01 in. (0.25 mm).

b. A measuring rod of 5 ft (1.5 m) length to measure depth of the blast hole with an accuracy of 0.1 in. (2.5 mm).

c. A steel straightedge of 2-ft (0.6-m) length to provide a reference line at the collar for depth measurements.

d. A canvas sheet 5 ft by 5 ft (1.5 m by 1.5 m), to collect drill cuttings. A hole should be cut at the center of the canvas sheet with a diameter equal to the diameter of the drill.

e. A balance of sufficient capacity to weigh the cuttings with an accuracy of 1.0 g.

PROCEDURE

30. a. An area is selected where the rock surface is flat and horizontal.

b. The multicone separator of the drilling machine is cleared of dust from previous drilling.

c. The test area is cleaned of loose rock and the canvas placed on the ground with the hole in the canvas directly over the blast hole.

d. A hole is drilled to a depth of between 3 and 5 ft (0.9 and 1.5 m).

e. The drill is raised after the cuttings have been carefully pushed back from around the drill rod.

f. The cuttings are weighed and the dust collected in the multicone separator.

g. The diameter of the hole is measured twice at right angles to each other and the average measurement is used to calculate volume.

h. The straightedge is placed along any diameter and the depth of the hole from the straightedge at the centre and at half points of both radii is measured. Repeat the measurement along the diameter perpendicular to the first. The average depth is used to calculate volume.

31. Steps in paragraph 27 are repeated for at least two additional holes within the same formation.

CALCULATION

32. The in situ bulk density or in situ unit weight of the rock is calculated as follows:

$$\gamma = \frac{W}{V}$$

where, W = weight of the cuttings and dust originating from the blast hole, and

V = volume of the blast hole.

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