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METHODS OF TEST FOR SOILS

PART XXXV MEASUREMENT OF NEGATIVE PORE WATER PRESSURE

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Indian Standard

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0. FOREWORD

0.1 This Indian Standard (Part XXXV) was adopted by the Indian Standards Institution on 21 February 1974, after the draft finalized by the Soil Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 With a view to establish uniform procedures for the determination of different characteristics of soils and also for facilitating a comparative study of the results, the Indian Standards Institution is bringing out the Indian Standards methods of test for soils (IS : 2720) which will be published in parts. This part (Part XXXV) deals with the measurement of negative pore water pressure. In partially saturated soils all the three phases, namely, solid, liquid and gas exist; the liquid phase is usually water and the gaseous phase usually air. At the interfaces of air and water, the surface tension of water is operative, the interfaces are curved, and water exists at a pressure lower than the pressure in the air. When air pressure is atmospheric water pressure is, consequently, less than atmospheric, or negative, that is, water is in a state of tension. This negative pore water pressure tends to hold soil particles together, it thus imparts rigidity and strength to soil.

0.3 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard (Part XXXV) lays down the method for determining the negative pore water pressure in partially saturated soils. For pressures in the range of 0 to $-$ 0·75 kg/cm^2 the measurement can be obtained directly. For this range as well as for greater negative pressures, measurement is possible in soils in which air continuity exists and the measurement

*Rules for rounding off numerical values (*revised*).

is achieved indirectly by the axis translation technique by artificially increasing pore air pressure and ambient pressure until pore water pressure is in the positive range. The maximum magnitude of the measurement thus possible is limited to the air entry value of the fine ceramic porous stone used.

2. TERMINOLOGY

2.1 For the purpose of this standard the terminology given in IS : 2809-1972* shall apply.

3. APPARATUS

3.1 The set up of the apparatus as shown in Fig. 1 is sufficient for both direct measurement of negative pore water pressure as well as measurement of pore water pressure using the axis translation technique.

3.2 For direct measurement of negative pore water pressure it is not necessary to apply cell pressure or air pressure. Valves A_1 and C_1 are thus kept closed during the measurement and the apparatus connected to them is redendant. For the same reason, the polyester fabric discs (13), the coarse porous stone (12), and the top cap (6) with the air lead are unnecessary and should be replaced by just an ordinary top cap.

3.3 For indirect measurement of negative pore water pressure the balancing manometer (1) is unnecessary; valves D_3 and D_5 can thus be left closed.

3.4 The apparatus consists of the following:

3.4.1 *Balancing Manometer* — A polythene U-tube half filled with mercury (1 in Fig. 1).

3.4.2 *Null Indicator* — A perspex block having a U-tube with a bore dia of 1·5 mm (3 in Fig. 1).

3.4.3 *Water Bottle* — (5 in Fig. 1).

3.4.4 *Top Cap* — Two caps, one with and one without an air lead connection (6 in Fig. 1).

3.4.5 *Rubber Rings* — of circular cross section to suit the diameter of the end caps (7 in Fig. 1).

3.4.6 *Seamless Rubber Membrane* — in the form of a tube, open at both ends of internal diameter equal to the specimen diameter and of length 50 mm greater than the height of the specimen. The membrane thickness should be selected having regard to the size, strength and nature of the soil. A thickness of 0·2 to 0·3 mm is normally satisfactory (8 in Fig. 1).

*Glossary of terms and symbols relating to soil engineering (*first revision*).

3.4.7 *Fine Ceramic Porous Stone* — A ceramic stone 32 mm in dia and 10 mm thick with an air entry value higher than the absolute value of the negative pore water pressure that has to be measured (10 in Fig. 1).

3.4.8 *Air Lead* — A flexible, high pressure polythene tube of 1 mm internal diameter (11 in Fig. 1).

3.4.9 *Coarse Porous Stone* — diameter 38 mm; 6 to 10 mm thick (12 in Fig. 1).

3.4.10 *Polyester Fabric Discs* — Two discs of polyester fabric 38 mm dia (13 in Fig. 1).

3.4.11 *Triaxial Cell* — with a pedestal about 38 mm in dia. The cell should have two pore water lines through the pedestal and two line through the base; one line to apply cell pressure and one line to connect air pressure load. Each line shall be fitted with a valve whose operation produces no volume change in the line. The pedestal should have a recess of dia 35 mm and depth 10 mm so that a fine ceramic porous stone can be placed and sealed in the recess (14 in Fig. 1).

3.4.12 *Pressure Gauge* — for measuring air pressure with a least count of 0·1 kg/cm^2 and a capacity of least 1 kg/cm^2 greater than the air entry value of the fine ceramic porous stone (15 in Fig. 1).

3.4.13 *Air Pressure Regulator* — which can supply air at a constant pressure with a precision of 0·05 kg/cm^2 (16 in Fig. 1).

3.4.14 *Air Filter* — capable of intercepting fine dust particles and the moisture in the air supply (17 in Fig. 1).

3.4.15 *Burette* — Least count 0·1 ml and capacity 100 ml (18 in Fig. 1).

3.4.16 Calibrated pressure mercury manometer, pressure gauge, screw control cylinder, and self-compensating mercury pot system properly connected to each other as in triaxial testing equipment (*X* in Fig. 1).

3.4.17 Pressure gauge, screw control cylinder, and self compensating mercury pot system properly connected to each other, and a reservoir of de-aired water as in triaxial testing equipment (*Y* in Fig. 1).

3.4.18 *Air Compressor* — or alternately any source of compressed air (*Z* in Fig. 1).

3.4.19 *Tubing and Valves* — high pressure polythene tubing and no-volume-change valves.

3.4.20 *Accessories* — For preparation of soil specimens, extrusion, trimming and for measurement of size, weight, water content, etc.

3.5 Use of the balancing manometer during direct measurement of negative pore water pressure enables positive pressure to be maintained in almost the entire pore water pressure measuring system. The zone in which water is subjected to negative pressure is confined to the null indicator and the pore water line between the level of mercury in the balancing manometer near valve D_3 to valve B_1. The volume of water in this zone is susceptible to cavitation and therefore shall be kept to a minimum. It is necessary, therefore, to locate valve B_1 as near the cell as possible, to locate the null indicator as near the cell as possible and to locate the balancing manometer as near the null indicator as possible. It shall be ensured that the water in this zone is as thoroughly de-aired as possible.

3.6 As far as possible, the measurements should be made in an environment in which the ambient temperature is kept constant.

4. PROCEDURES FOR COMMISSIONING APPARATUS

4.1 Placement and Sealing of Fine Ceramic Porous Stone

4.1.1 Ensure that the flat surfaces of the stone have zero curvature.

4.1.2 Place stone centrally in the recess in the pedestal of the triaxial cell.

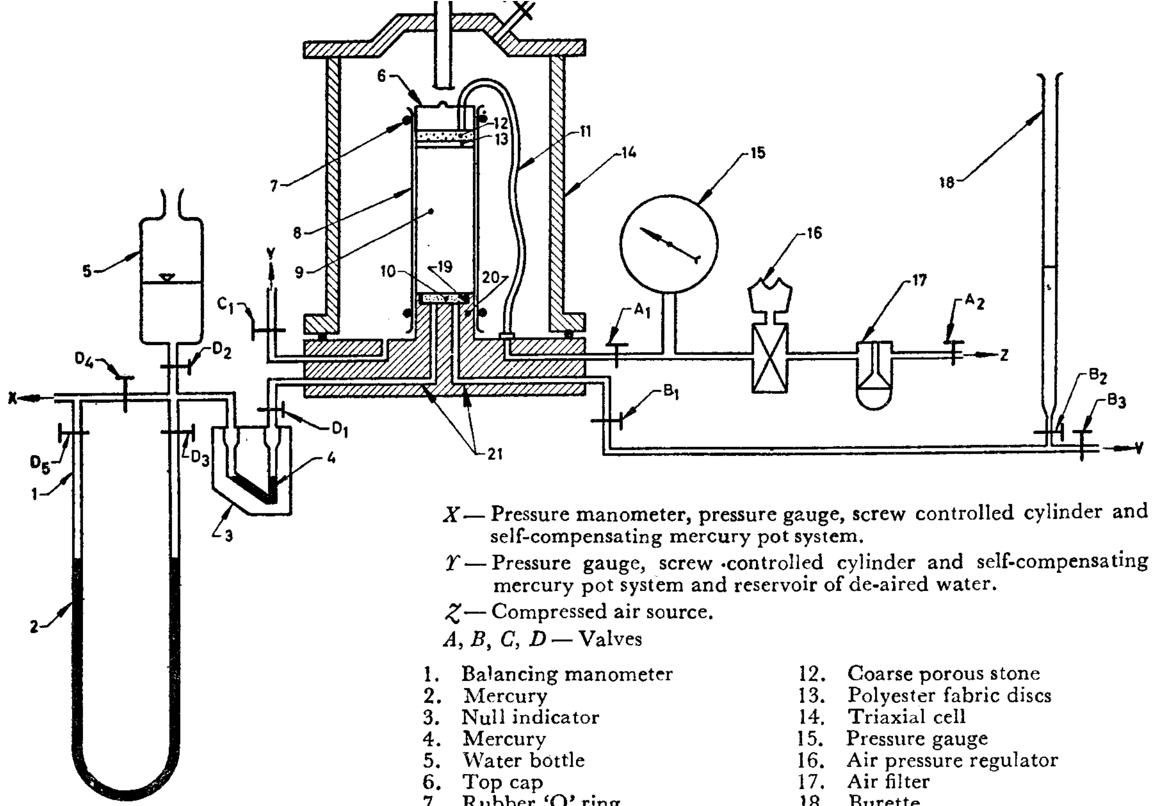
4.1.3 Fill annular groove between stone and recess walls with epoxy resin seal ensuring that no air gets trapped in the groove.

4.1.4 Let epoxy resin seal set for 24 hours.

4.2 Saturation of Fine Ceramic Porous Stone and De-airing of Pore Water Pressure Lines — Measurement of negative pore water pressure is not possible unless the fine ceramic porous stone is saturated with de-aired water and the pore pressure lines are thoroughly de-aired and filled with de-aired water. The saturation and de-airing process is thus the most important step in commissioning the apparatus. The process is described below and the description assumes that all valves are initially closed.

4.2.1 De-air water by boiling and subjecting it to vacuum. Quantity of water to be de-aired should be sufficient to fill about four triaxial cells. The mercury pot system and the screw controlled cylinder in *X* and *Y* should be filled up with this water (for explanation regarding *X* and *Y* (*see* Fig. 1).

4.2.2 Open valve C_1 and fill the empty cell (no top cap assembly and no soil sample) with de-aired water when the water is still warm from having been boiled. Apply cell pressure of about 6 kg/cm².



X — Pressure manometer, pressure gauge, screw controlled cylinder and self-compensating mercury pot system.

Y — Pressure gauge, screw controlled cylinder and self-compensating mercury pot system and reservoir of de-aired water.

Z — Compressed air source.

A, *B*, *C*, *D* — Valves

1. Balancing manometer
2. Mercury
3. Null indicator
4. Mercury
5. Water bottle
6. Top cap
7. Rubber 'O' ring
8. Rubber membrane
9. Soil sample
10. Fine ceramic porous stone
11. Air lead
12. Coarse porous stone
13. Polyester fabric discs
14. Triaxial cell
15. Pressure gauge
16. Air pressure regulator
17. Air filter
18. Burette
19. Epoxy resin seal
20. Pedestal on base of triaxial cell
21. Pore water lines

FIG. 1 A TYPICAL ASSEMBLY OF APPARATUS FOR MEASUREMENT OF NEGATIVE PORE WATER PRESSURE

4.2.3 Open valves B_1 and B_2 and let the water flow through the ceramic stone, the pore water line into the burette. Flush water equivalent to about half the volume of the cell then close valves B_1 and B_2.

4.2.4 Open valves D_1 and D_2 and tilt the null indicator so that mercury is out of the flow circuit and let the water flow through the ceramic stone, the pore water line, the null indicator into the water bottle through valve D_2. Flush water equivalent to about half the volume of the cell then close valves D_1 and D_2.

4.2.5 Set pressure beyond valve B_3 in Y equal to 5 kg/cm^2, open valves B_1 and B_3 and let the water flow through the ceramic stone the pore water line into the mercury pot system in Y. Flush water equivalent to about half the volume of the cell then close valves B_1 and B_3.

4.2.6 Set pressure beyond valves D_4 and D_5 in X equal to 5 kg/cm^2, open valves D_1 and D_4 and with the null indicator tilted so that mercury is out of the flow circuit let the water flow through the ceramic stone, the pore water line, the null indicator into the mercury pot system in X. Flush water equivalent to about half the volume of the cell then close valves D_1 and D_4.

4.2.7 Open valves B_1 and B_2 (*see* Note), reduce pressure in cell to zero, empty the cell of water, let water seep slowly from burette through valves B_2 and B_1 to ceramic stone. The surface of ceramic stone should always have water standing on it. The burette should always have de-aired water in it at an elevation little higher than that of the ceramic stone.

NOTE — At this stage by measuring flow of water per unit time into the burette, and by knowing the cell pressure, the cross-section area and the thickness of the ceramic stone, the permeability of the ceramic stone should be determined. If the permeability so determined is markedly higher than that specified by the manufacturer it may be on account of a leak in the araldite seal. The leak should be plugged and the seal perfected before proceeding.

4.3 Measurement of air entry value of fine ceramic porous stone.

4.3.1 After the ceramic stone is saturated and pore water lines de-aired as indicated in **4.2** with valves B_1 and B_2 open and all other valves closed, wipe off excess water from surface of ceramic stone and assemble empty cell (no top cap assembly and no soil sample).

4.3.2 Record level of water in burette which should be a little higher than the elevation of the ceramic stone.

4.3.3 Open valves A_2 and A_1 and apply air pressure of 0·5 kg/cm^2 through cell on top of ceramic stone. After half an hour record reading in burette which may be little higher than initial reading as air under pressure pushes any little excess water on top of ceramic stone into burette.

4.3.4 Raise air pressure in increments of 0·5 kg/cm² reducing the increment to 0·1 kg/cm² as the air pressure approaches the expected air entry value of the ceramic stone. Let each successive value of the air pressure act on the ceramic stone for half an hour and before applying the next increment of air pressure record the level of water in burette.

4.3.5 The reading in the burette will remain constant for all air pressures less than the air entry value of the ceramic stone unless the epoxy resin seal has a leak (*see* Note). When the air pressure equals the air entry value of the ceramic stone air will enter the stone and push the water in the pore water line into the burette raising the level of the water in the burette. The pressure at which one observes the level of the water in the burette rising is thus the air entry value of the ceramic stone.

NOTE — If the measured air entry value as given in **4.3** is very much lower than that specified by the manufacturer it may be on account of a leak in the epoxy resin seal. The leak should be plugged and the seal perfected before proceeding.

4.3.6 During determination of the air entry value of the ceramic stone, air enters the ceramic stone and the pore water lines. The system has therefore to be saturated and de-aired again as indicated in **4.2** before using it for measuring negative pore water pressure in soil samples.

NOTE — The air entry value of a ceramic stone needs to be measured only once to determine the range of utility of that stone.

5. SOIL SAMPLE FOR TEST

5.1 Negative pore water pressure can be measured by this method both for soil samples obtained by sampling from the field as well as for soil samples prepared in the laboratory by compaction, remoulding, or any other process. The sample should be trimmed to a diameter equal to the diameter of the pedestal of the triaxial cell. Any height of the sample that is convenient is admissible.

6. PROCEDURE FOR DIRECT MEASUREMENT OF NEGATIVE PORE WATER PRESSURE

6.1 Prepare apparatus as shown in Fig. 1 and as indicated in **3.2**.

6.2 Saturate ceramic stone and de-air pore water lines as indicated in **4.2**.

6.3 Ensure that there are no leaks in valves B_1, D_1, D_3, D_4 and D_5, or in any connection on the pore water lines or in the system indicated as X in Fig. 1.

6.4 Initially it is as assumed that all valves are closed except B_1 and B_2 and water is gradually flowing from burette to the surface of the ceramic stone.

6.5 Open valves D_4 and D_1 and using the screw control cylinder in X bring mercury to desired level in the limb of the U-tube closer to valve D_1 in the null indicator. Mark the position of the mercury as null position, close valves B_1, D_1 and D_4. Ensure that some water is standing on top of ceramic stone.

6.6 With water level in the water bottle a little above the ceramic stone, open valves D_2, D_3 and D_5 and using the screw control cylinder in X push the mercury up in the limb of the U-tube closer to valve D_3 in the balancing manometer until the pressure measuring systems in X, that is, the pressure gauge and the mercury manometer record a pressure of 1·0 kg/cm². Close valve D_2.

6.7 Wipe off excess water on the top of the ceramic stone. Put a pinch of wet soil (same soil as in soil sample whose negative pore water pressure is to be measured) on the top of the ceramic stone and spread it on the top of the ceramic stone, then immediately place the soil sample on the ceramic stone (the pinch of wet soil assists in proper seating of the soil sample on the ceramic stone). Place the top cap on the soil sample and envelop it with a rubber membrane sealing the rubber membrane with rubber rings at the rop cap and at the pedestal to prevent moisture loss from the sample by evaporation. Assemble the cell and fill it with just enough water so that the sample is under water.

6.8 Open Valve D_1 — As soon as valve D_1 is opened the sample will begin to suck water from the porous stone which will show up as an upward movement of the mercury in the limb of the U-tube closer to valve D_1 in the null indicator. This movement of mercury in the null indicator should be prevented and null position maintained by reducing the pressure in X by operating the screw controlled cylinder in X.

6.9 Adjust pressure in X until equlibrium is achieved and there is no tendency of the mercury in the null indicator to shift from the null position. Record this pressure in X as equlibrium pressure in kg/cm².

6.10 The absolute value of the negative pore water pressure in the soil sample is (1·0 — equilibrium pressure) kg/cm².

6.11 Open valves B_1 and D_2, dis-assemble the soil sample, reduce pressure in X to zero, close valves D_1, D_2, D_3, D_4 and D_5. Let water flow from burette to top of ceramic stone, clean top of stone. Equipment is now ready for next measurement, unless there is an indication to suggest that air has come out of solution in the pore water line, if so, the system must first be again de-aired as indicated in **4.2** before making the next measurement.

7. PROCEDURE FOR INDIRECT MEASUREMENT OF NEGATIVE PORE WATER PRESSURE USING THE AXIS-TRANSLATION TECHNIQUE

7.1 Prepare apparatus as shown in Fig. 1 and as indicated in **3.3**.

7.2 Saturate ceramic stone and de-air pore water lines as indicated in **4.2**.

7.3 Ensure that there are no leaks in the various valves, connections, etc.

7.4 Initially it is assumed that all valves are closed except B_1 and B_2 and water is gradually flowing from burette to the surface of the ceramic stone.

7.5 Open valves D_4 and D_1 and using the screw control cylinder in X bring mercury to desired level in the limb of the U-tube closer to valve D_1 in the null indicator, mark the position of the mercury as null position; close valve D_4 and partially close valve B_1 such that the rate of flow of water from the burette to the surface of the ceramic stone is barely perceptible.

7.6 Wipe off excess water on the top of the ceramic stone. Observe the reading of the water level in the burette. Put a pinch of wet soil (same soil as in soil sample whose negative pore water pressure is to be measured) on top of ceramic stone and spread it on top of ceramic stone then immediately place soil sample on ceramic stone (the pinch of wet soil assists in proper seating of soil sample on the ceramic stone).

7.7 As soon as sample is placed on the ceramic stone it will begin to suck water from it which will show up as a downward movement of water in burette since valve B_1 is partially open. The volume of water so sucked up by the soil sample must be minimized by rapidly proceeding with steps as described in **7.8** and **7.9** which elevate the pore water pressure in the sample to the positive range.

7.8 Place two discs of polyester fabric on top of soil sample followed by the coarse porous stone which in turn is followed by the top cap. Envelope the sample with rubber membrane and seal it with rubber '0' rings. Connect the air lead to the base of the cell and assemble the cell. Open valve C_1 and fill the cell with water.

7.9 Open valves A_1 and A_2 and simultaneously apply pore air pressure through valve A_1 to the soil sample and cell pressure through valve C_1. The cell pressure and pore air pressure applied should be of equal magnitude and may be applied in increments of 0·5 kg/cm². In a soil in which pore air exists as a continuous medium, that is, the air phase in different pores is interconnected, increase in cell pressure and pore air pressure by a certain magnitude will induce an increase in pore water pressure of the same magnitude. Hold each applied increment of cell pressure and pore air pressure long enough to ascertain whether soil is sucking water from burette or not. Once the cell pressure and pore air pressure are raised sufficiently to have neutralized the negative pressure in the pore water of the soil sample, water will be seen to rise in burette. When this is observed to occur, close valve B_1 and record the level of the water in the burette. The difference in this reading and the initial reading (as in **7.6**) in the burette represents the water absorbed by the soil in the process of setting up the sample. The negative pore water pressure of the sample as set up is thus different from that of the sample prior to being set up. This deviation is reduced by minimizing the water absorbed by the sample during set up as noted in **7.7**.

7.10 With valve B_1 closed the positive pore water pressure produced in the sample will tend to push mercury down from the null position in the null indicator. This is to be prevented and null position maintained by increasing pressure in X. The null position should be maintained until equilibrium is achieved. During the process of achieving equilibrium it may be necessary to further increase the cell pressure and the pore air pressure, so as to keep the pore water pressure in the positive range.

7.11 The absolute value of the negative pore water pressure in the soil sample is equal to the applied pore air pressure minus the measured positive pore water pressure at equilibrium.

7.12 Having determined the negative pore water pressure in the soil sample as in **7.11** it is necessary to check that air continuity did indeed exist in the soil sample. This is accomplished by once again increasing the cell pressure and the pore air pressure by the same amount and observing the increase in pore water pressure as null condition is maintained. If the pore water pressure increases by an amount equal to the increase in cell pressure and air pressure, then air continuity exists and the determination of negative pore water pressure in **7.11** is valid.

7.13 Close valve D_1, partially open valve B_1, reduce cell pressure and pore air pressure to zero, drain water from cell, close valve C_1, A_1 and A_2, and dis-assemble cell and soil sample. Open valve B_1 completely and let water flow from burette to top of ceramic stone. Clean top of stone. Equipment is now ready for the next measurement, unless there is an indication to suggest that air has come out of solution in the pore water line; if so, the system should first be again de-aired as given in **4.2** before making the next measurement.

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