IS:2720 (Part XV)-1965

(Reaffirmed 1997)

86

Indian Standard

METHODS OF TEST FOR SOILS

PART XV DETERMINATION OF CONSOLIDATION PROPERTIES

Fifth Reprint MARCH 1983
(Incorporating Amendments No. 1 and 2)

UDC 624.131.43:539.383

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 4 May 1965

Indian Standard

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Soil Engineering Sectional Committee, BDC 23

(*Continued on page* 2)

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(*Continued from page* 1)

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Indian Standard

METHODS OF TEST FOR SOILS

PART XV DETERMINATION OF CONSOLIDATION PROPERTIES

0. FOREWORD

0.1 This Indian Standard (Part XV) was adopted by the Indian Standards Institution on 18 February 1965, 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 establishing 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 this 'Indian Standard methods of test for soils (IS:2720)' which will be published in parts. This part [IS:2720 (Part XV)-1965] deals with the method of test for the determination of consolidation properties of soils. The main purpose of consolidation tests is to obtain soil data which are used in predicting the rate and the amount of settlement of structures. The two most important soil properties furnished by a consolidation test are compression index (C_c) which indicates the magnitude of compression and the coefficient of consolidation (c_v) which indicates the rate of compression under a load increment. The data from laboratory consolidation test make it possible to plot a stress-volume strain curve, which gives useful information about the pressure history of the soil. The Terzaghi theory of consolidation is used for extrapolating laboratory consolidation test results in order to predict the settlements of structures in the field.

0.3 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in this field in this country. Assistance has been derived from Central Board of Irrigation and Power (India) Publication No. 42, Standards for testing soils.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS:2-1960*. The number of significant places retained in the

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

rounded off value should be the same as that of the specified value in this standard.

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1. SCOPE

1.1 This standard covers the method for conducting one-dimensional consolidation test using either fixed or the floating ring on soils both disturbed and undisturbed in the saturated condition for determining the rate of consolidation of the soil under a normal load and the degree of consolidation at any time.

2. TERMINOLOGY

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

3. APPARATUS

3.1 Loading Device — a suitable device for applying vertical loads to the soil specimen. The loading may be done either by a jack with load measurement by platform scale or by the lever system on which weights of known magnitude can be hung. The loading device should be capable of maintaining specified pressure for long periods of time with an accuracy of ± 1 percent of the applied pressure. It should permit application of a given load increment within a period of two seconds without impact. The lever system shall be such that no horizontal force is imposed on the specimen at any stage during testing and should ensure verticality of all loads applied to the specimen.

3.2 Consolidometer — a device to hold the sample in a ring either fixed or floating with porous stones on each face of the sample. A consolidometer shall also provide means for submerging the sample, for applying a vertical load and for measuring the change in the thickness of the specimen. The provision for fixing of the dial gauge shall be rigid; in no case shall the dial gauge be fixed to a cantilivered arm. Suitable provision shall be made to enable the dial gauge to be fixed in such a way that the dial gauge records accurately the vertical compression of the specimen. The consolidometer shall allow compression of specimen to 50 percent of its original thickness.

The consolidometer shall conform to the requirements given under **3.2.1** to **3.2.3**.

3.2.1 *Specimen Diameter* — The specimen shall be 60 mm in diameter (specimens of diameters 50, 70 and 100 mm may also be used in special cases).

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

3.2.2 *Specimen Thickness* — The specimen shall be at least 20 mm thick in all cases. However, the thickness shall not be less than 10 times the maximum diameter of the grain in the soil specimen. The diameter to thickness ratio shall be a minimum of 3.

3.2.3 *Ring* — The ring shall be made of a material which is non-corrosive in relation to the soil tested. The inner surface shall be highly polished or coated with a low-friction material. The thickness of the ring shall be such that under assumed hydrostatic stress conditions in the sample the change in diameter of the ring will not exceed 0·03 percent under the greatest load applied during the test.

The ring shall have one edge bevelled suitably so that the sample is pressed into the ring with least disturbance. This ring should be placed with its cutting edge upwards in the consolidometer and clamped with a special clamp which should in no way damage the sharp edge. The clamp should be made circular with a central hole equal in diameter of the porous stone and should be perfectly concentric with the sample.

3.3 Porous Stones — The stones shall be of silicon carbide, aluminium oxide or porous metal and of medium grade. It shall have a high permeability compared to that of the soil being tested.

The diameter of the top stone shall be 0·2 to 0·5 mm less than the internal diameter of the ring.

The stone thickness shall be sufficient to prevent breaking. The top stone shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the stone. The loading plate shall have suitable holes for free drainage of water.

3.4 Moisture Room — for storing samples and for preparing samples in climates where there is likelihood of excessive moisture loss during preparation (optional).

3.5 Soil Trimming Tools — like fine wire-saw, knife, spatula, etc, for trimming sample to fit into the inside diameter of the consolidometer ring with a minimum of disturbance.

3.6 Water Reservoir — to saturate the soil sample.

3.7 Balance — sensitive to 0·01 g.

3.8 Dial Gauge — accurate to 0·002 mm.

3.9 Oven — thermostatically controlled oven with interior of non-corroding material to maintain the temperature between 105 and 100°C.

3.10 Desiccator — with any desiccating agent other than sulphuric acid.

3.11 Moisture Content Cans

4. PROCEDURE

4.1 Preparation of the Soil Specimen

4.1.1 *Preparation of Specimen from Undisturbed Soil Samples* — The container shall be cleaned and weighed empty. About three centimetres or more if desired from one end of the undisturbed soil sample shall be cut off and rejected. The specimen shall be cut off either from the undisturbed tube samples or from block sample, the latter generally being more representative of the field conditions. In either case the consolidation ring should be gradually inserted in the sample by pressing with hands and carefully removing the material around the ring. The soil specimen so cut shall project as far as one centimetre on either side of the ring. The specimen shall then be trimmed smooth and flush with the top and bottom of the ring. Any voids in the specimen caused due to removal of gravel or limestone pieces, shall be filled back by pressing lightly the loose soil in the voids, care being taken to see that the permeability of the specimen is not affected. The container ring shall be wiped clear of any soil sticking to the outside and weighed again with the soil. The whole process should be quick to ensure minimum loss of moisture and if possible shall be carried out in the moisture room. Three representative specimens from the soil trimmings shall be taken in moisture content cans and their moisture content determined in accordance with IS : 2720 (Part II)-1973*.

Organic soils, such as peat and those soils that are easily disturbed, such as gravelly soils may be transferred directly from the sampling tube to the ring where the ring and tube sizes have been suitably selected for this purpose.

4.1.2 *Preparation of Specimen from Representative Soil Samples* — In cases where it is necessary to use disturbed soil samples, the soil sample shall be compacted to the desired (or field) density at the desired (or field) water content in a larger container and the required specimen for the test prepared as specified in **4.1.1** from this compacted sample.

NOTE 1 — While preparing the specimen, attempt shall be made to have the soil strata oriented in the same direction in the consolidation apparatus as they were or will be oriented in practice. The orientation shall also be such that the laboratory test normally compresses the soil in the same direction relative to the soil strata as the applied load in the field.

NOTE 2 — In trimming the soil, great care shall be taken to handle the specimen delicately with the least pressure applied to the soil. Due to the small thickness of the specimen in the ring, these specimens are always in the danger of being disturbed during trimming.

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*Methods of test for soils: Part II Determination of water content (*second revision*).

4.2 Assembly

4.2.1 The porous stones shall be saturated. All surface of the consolidometer which are to be enclosed shall be moistened. The porous stones shall be saturated by boiling in distilled water for at least 15 minutes. The consolidometer shall be assembled with the soil specimen (in the ring) and porous stones at top and bottom of the specimen, providing a filter paper (Whatman No. 1 or equivalent) between the soil specimen and the porous stone. The loading block shall then be positioned centrally on the top porous stone.

4.2.2 This assembly shall then be mounted on the loading frame such that, the load when applied is transmitted to the soil specimen through the loading cap. The assembly shall be so centred that the load applied is axial.

4.2.3 In the case of the lever loading system, the apparatus shall be properly counterbalanced. If a jack with load measurements by platform scales is used as the loading system, the tare weight with the empty consolidation apparatus, excluding those parts which will be on top of the soil specimen; which rest on the platform shall be determined before filling the ring with the soil and this tare weight shall be added to the computed scale loads required to give the desired pressures at the time of loading the soil specimen.

4.2.4 The holder with the dial gauge to record the progressive vertical compression of the specimen under load, shall then be screwed in place and adjusted in such a way that the dial gauge is near the beginning of its release run, allowing sufficient margin for the swelling of the soil, if any.

4.2.5 The system shall be connected to a water reservoir with the level of water in the reservoir being at about the same level as the soil specimen and water allowed to flow in the sample. The soil shall be allowed to saturate.

4.2.6 An initial setting load shall be chosen by trial such that there is no swelling of the sample. However, it shall not be less than 50 g/cm^2. The load shall be allowed to stand until there is no change in the dial gauge reading for two consecutive hours or for a maximum of 24 hours.

NOTE — For very soft soils a setting load of 25 g/cm^2 or less may be desirable.

4.3 Loading for the Compression Test

4.3.1 The compression dial reading about 24 hours after the application of the initial setting load specified in **4.2.6** shall be noted. Then a normal load to give the desired pressure intensity shall be applied to the soil starting a stop watch simultaneously with loading. The dial gauge reading shall be recorded after various intervals of time. For the purpose of record the form given in Appendix A may be used and the dial gauge readings noted at total elapsed time since starting shown therein (*see* Note).

NOTE — The time suggested for readings give a good spacing of points on the plot used for the square root fitting method. Readings may also be taken at other time intervals and plotted. Readings at lesser intervals or even a larger test specimen may be required for soils which compress very rapidly.

4.3.2 The dial gauge readings shall be taken until 90 percent consolidation is reached. Thereafter, occasional observations shall be continued until a sufficient number have been taken for the log fitting method.

NOTE — For soils which have slow primary consolidation, loads should act for at least 24 hours and in extreme cases or where secondary consolidation must be evaluated, much longer.

4.3.3 At the end of the period specified in **4.3.2** the compression dial reading and the corresponding time reading shall be taken and the load intensity on the soil specimen doubled. Dial and time readings shall be taken as indicated in **4.3.1**. Then successive load increments shall be applied and the observations repeated for each load till the specimen has been loaded to the desired intensity (*see* Note).

NOTE — The usual sequence of loading is 0·1, 0·2, 0·4, 0·8, 1·6, 3·2 and 6·4 kg/cm^2. Smaller increments may be desirable for very soft soil samples. Alternatively 6, 12, 25, 50, 100 and 200 percent of the maximum field loading may be used. An alternative loading or reloading schedule may be employed that reproduces the construction stress changes, or obtains better definition of some part of the stress-void ratio curve, or aids in interpreting the field behaviour of the soil. This should be clearly indicated in the report of test results.

4.3.4 After the last load has been on, for the required period, the load should be decreased to one-fourth the value of the last load and allowed to stand for 24 hours. No time dial readings are normally necessary during the rebound. If swelling information is required, more complete data as required in Appendix A may be taken. The load shall be further reduced in steps of one-fourth the previous intensity till an intensity of 0·1 kg/cm^2 is reached and the observations repeated as required. If data for repeated loading is desired the load intensity may now be increased in steps of double the immediately preceding value and the observations repeated.

4.3.5 Throughout the test, the container gutter shall be kept filled with water in order to prevent desiccation and to provide water for the rebound expansion.

4.3.6 After the final reading has been taken for the 0·1 kg/cm^2 the load shall be reduced to the initial setting load, kept for 24 hours and the final reading of the dial gauge noted.

4.3.7 When the observations mentioned above are completed, the soil specimen assembly shall be quickly dismantled, the excess surface water on the soil specimen carefully removed by blotting, and the ring with the consolidated soil specimen weighed. The soil shall then be dried to constant weight in an oven maintained at 105 to 110°C and the dry weight recorded.

5. CALCULATIONS AND REPORT

5.1 Record — The observations shall be recorded suitably. The forms given in Appendix A are recommended.

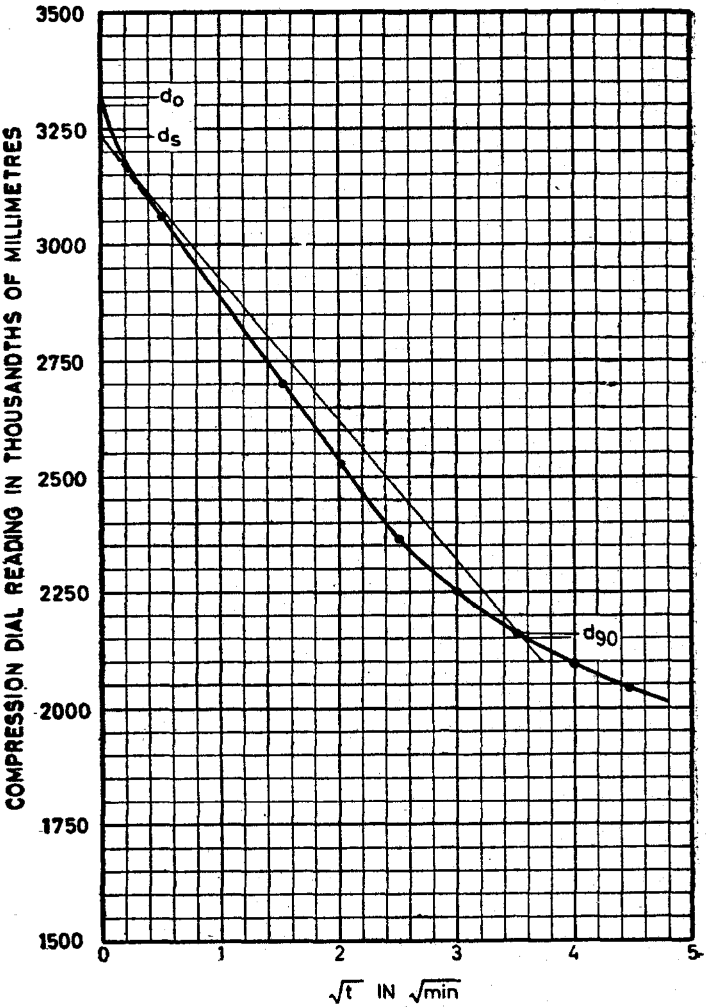
5.2 Calculations

5.2.1 *Fitting Methods*

a) *Square root method* (*see* Fig. 1A) — The observations recorded in Form 1 given in Appendix A shall be plotted with square root of elapsed time as abscissa and the dial gauge readings as ordinates. A smooth curve shall be drawn joining these points. The initial straight portion of the curve (the first one or two points may not be on this straight line) shall be extended back to intersect the line of zero time and the corrected zero point 'd_s' obtained. Through 'd_s' a straight line having all abscissae 1·15 times as large as the corresponding values on the straight line portion of the curve shall be drawn cutting the time-compression curve at a point, the ordinate 'd_{90}' of which corresponds to 90 percent compression and the abscissa of which gives $\sqrt{t_{90}}$, the square of which gives the time to 90 percent compression. From these the dial reading 'd_{100}' corresponding to 100 percent primary compression shall be calculated.

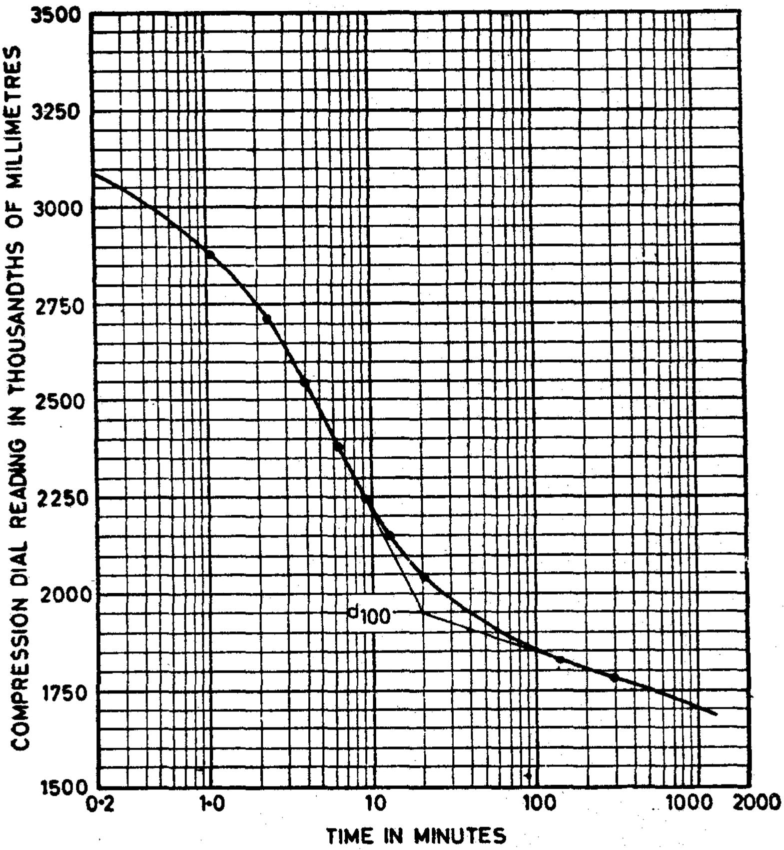
b) *Log method* (*see* Fig. 1B) — The compression dial readings shall be plotted against the log of time and a smooth curve drawn to pass through the points. The two straight portions of the curve shall be extended to intersect at a point, the ordinate of which gives 'd_{100}' corresponding to 100 percent primary compression. The corrected zero point 'd_s', shall be located by laying off above a point in the neighbourhood of 0·1 minute a distance equal to the vertical distance between this point and one at a time which is four times this value (*see* Note). The 50 percent compression point which is halfway between the corrected zero point and the 100 percent compression point, shall be marked on the curve and the reading on the time axis corresponding to this point t_{50}, time to 50 percent primary compression, shall be noted. The reading, on the dial gauge reading axis, corresponding to 100 percent compression gives 'd_{100}'.

NOTE — Several pairs of points with time ratios of 4 may be used; pairs up to 5 min/20 min or 10 min/40 min may be needed for soils of high plasticity. The corrected zero point may be based on the best value obtained from these pairs of points.



1A THE SQUARE ROOT OF TIME FITTING METHOD

FIG. 1 FITTING METHODS—*Contd*



1B THE LOGARITHM OF TIME FITTING METHOD

FIG. 1 FITTING METHODS

5.2.2 *Compression of the Specimen*

a) Initial compression = $d_o - d_s$

where

d_o = initial reading of dial gauge taken immediately before applying load, and corrected for elastic compression of apparatus (*see* Note), and

d_s = corrected zero point [*see* **5.2.1** (a) and (b)].

NOTE — Elastic compression of the apparatus may be determined by using a solid material such as steel in the ring instead of the soil specimen.

b) Primary compression $= d_s - d_{100}$

where

d_s = corrected zero point for a load applied in the test [*see* **5.2.1** (a) and (b)], and

d_{100} = reading corresponding to 100 percent compression at the same load [*see* **5.2.1** (a) and (b)].

c) Secondary compression $= d_{100} - d_f$

where

d_{100} = reading corresponding to 100 percent compression at a load used in the test [*see* **5.2.1** (a) and (b)], and

d_f = final reading corresponding to the same load at the end of 24 hours after application of the load.

d) *Total compression*—This is the sum of the initial, primary and secondary compression and is equal to $d_o - d_f$, where d_o and d_f have the the same meaning as described in **5.2.2** (a) and (c), respectively.

e) The initial, primary and secondary compression ratios may be calculated as the ratios of the respective compression to the total compression.

5.2.3 *Compression Index and Coefficient of Compressibility*—The equivalent height of soil solids shall be calculated as follows:

$$2H_o = \frac{W_s}{G_s \gamma_w A}$$

where

$2H_o$ = equivalent thickness of solids,

W_s = weight of soil solids as determined by oven drying the specimen at the end of the test (*see* **4.3.7**),

G_s = specific gravity of soil [determined in accordance with IS : 2720 (Part III)-1980*],

γ_w = unit weight of water, and

A = area of container ring.

From the initial thickness of the soil sample and the final dial gauge readings, the thickness $2H$ of the sample at the end of each application of load shall be calculated. The void ratio in each case shall be calculated as follows:

$$e = \frac{2H}{2H_o} - 1$$

*Methods of test for soils: Part III Determination of specific gravity (*first revision*).

where

e = void ratio,

$2H$ = thickness of specimen at the end of period specified in **4.3.2** after application of each load, and

$2H_0$ = equivalent thickness of solids.

From the calculated void ratios, a plot of void ratio 'e', versus log of pressure 'p', may be made.

The initial compression curve would be found to be a straight line at pressures above a certain value. The slope of this straight line portion of the curve shall be reported at the compression index C_c.

The coefficient of compressibility 'a_v' may be calculated as follows:

$$a_v = \frac{0{\cdot}435\ C_c}{p}$$

where

a_v = coefficient of compressibility,

C_c = compression index, and

p = the average pressure for the increment.

From the 'e' versus log 'p' curve the maximum intergranular pressure to which the soil has been previously consolidated may be approximately obtained as follows:

> The point of maximum curvature is located on the curve. At this point a horizontal line and a tangent to the curve are drawn. The angle formed between these two lines is bisected and this bisector is intersected by extending back the straight portion of the log 'p' versus 'e' curve which exists at the higher pressures. The pressure corresponding to the point of intersection may be taken as the approximate maximum pre-compression pressure.

5.2.4 *Coefficient of Consolidation* — The coefficient of consolidation at the desired pressure increment shall be calculated as follows:

a) $c_v = \dfrac{0{\cdot}848\ H^2}{t_{90}}$ (Taylor's method or Square root fitting method)

b) $c_v = \dfrac{0{\cdot}197\ H^2}{t_{50}}$ (Casagrande's method or Log fitting method)

where

c_v = coefficient of consolidation,

$2H$ = thickness of specimen at the beginning of period specified in **4.3.2** for each load,

t_{90} = time corresponding to 90 percent compression [*see* **5.2.1** (a)] in minutes, and

t_{50} = time corresponding to 50 percent compression [*see* **5.2.1** (b)] in minutes.

5.2.5 The permeability of the soil may be calculated as follows:

$$k = \frac{c_v \, a_v \, \gamma_w}{1 + e}$$

where

k = coefficient of permeability,
c_v = coefficient of consolidation (*see* **5.2.4**),
a_v = coefficient of compressibility (*see* **5.2.3**),
γ_w = unit weight of water, and
e = void ratio (*see* **5.2.3**).

APPENDIX A

(*Clauses* 4.3.1, 4.3.4, 5.1 *and* 5.2.1)

CONSOLIDATION TEST

FORM 1

PROJECT: DETAILS OF SOIL SAMPLE:

Date									
Pressure increment									
Time of starting									
Elapsed time in minutes	$\sqrt{t}$	Dial Gauge Readings							
0	0	d_0	d_0	d_0	d_0	d_0	d_0	d_0	d_0
0·25	0·5								
1	1								
2·25	1·5								
4	2								
6·25	2·5								
9	3								
12 25	3·5								
16	4								
20·25	4·5								
25	5								
36	6								
49	7								
64	8								
81	9								
100	10								
121	11								
144	12								
169	13								
196	14								
225	15								
256	16								
289	17								
324	18								
361	19								
400	20								
500	22·4								
600	24·5								
1 440	38								

(*Continued*)

CONSOLIDATION TEST — *Contd*

FORM 2

PROJECT: DETAILS OF SOIL SAMPLE:

Measurements of container ring:

Weight of container
Diameter (interior) of container
Area of container
Initial thickness of soil sample
Specific gravity of soils

Equivalent height of solid, $2H_o = \dfrac{W_s}{G_s \quad \gamma_w A}$

MOISTURE CONTENT

	Before test	After test
Wt. of container ring + Wet soil		
Wt. of container ring + Dry soil		
Wt. of ring		
Wt. of dry soil		
Wt. of water		
Moisture percent		
Degree of saturation		

Applied Pressure in kg/cm²	Final Dial Reading d_f	Change in Dial Reading	Thickness of Soil Sample $2H$	Equivalent Height of Voids $2H - 2H_0$	Void Ratio $e = \dfrac{2H}{2H_0} - 1$	Fitting Time S		c_v cm²/min		a_v	C_c	Permeability k	Remarks
						t_{50}	t_{90}	$\dfrac{0.197H^2}{t_{50}}$	$\dfrac{0.848H^2}{t_{90}}$				