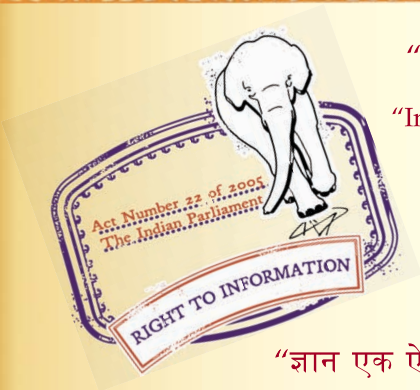
IS 2720-15 (1965): Methods of Test for Soils, Part XV: Determination of Consolidation Properties [CED 43: Soil and Foundation Engineering]



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IS : 2720 (Part 15) - 1986
(Reaffirmed 2002)

Indian Standard

METHODS OF TEST FOR SOILS

PART 15 DETERMINATION OF CONSOLIDATION PROPERTIES

(First Revision)

Second Reprint JULY 2001

UDC 624.138

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

Gr 5 *May* 1987

Indian Standard

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PART 15 DETERMINATION OF CONSOLIDATION PROPERTIES

(First Revision)

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Indian Standard

METHODS OF TEST FOR SOILS

PART 15 DETERMINATION OF CONSOLIDATION PROPERTIES

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part 15) (First Revision) was adopted by the Indian Standards Institution on 28 August 1986, 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 determination of different characteristics of soils and also to facilitate a comparative study of the results, this standard is being published in various parts. This standard (Part 15) deals with the method of test for the determination of consolidation characteristics of soils. The main purpose of the consolidation test is to obtain soil data which is used in predicting the rate and the amount of settlement of structures. The two most important soil properties furnished by a consolidation test are the coefficient of compressibility (a_v), through which one can determine the magnitude of compression, and the coefficient of consolidation (c_v) which enables the determination of the rate of compression under a load increment. The data from laboratory consolidation test also gives useful information about the stress 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 This standard was first published in 1965. The revision has been prepared, based on experience gained in use of this test in the past 20 years. The principal modifications made are in respect of giving requirements in detail for the consolidation cell, preparation of test samples, loading and proforma for recording and calculation.

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, shall be rounded off in accordance with IS : 2-1960*.

*Rules for rounding off numerical values (revised).

The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard covers the method for conducting one dimensional consolidation test using either fixed or the floating ring for determining the consolidation characteristics of soil.

2. TERMINOLOGY

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

3. APPARATUS

3.1 Consolidation Ring

3.1.1 The ring shall be rigid and made of a non-corrosive material. The inner surface shall be smooth and highly polished, and coated with a low friction material in order to minimize wall friction. A teflon coating is suitable for this purpose, alternatively, silicon grease is good for stiff and medium soils while a thick oil may be used for very soft soils.

3.1.2 The ring shall be provided with a cutting edge in order to facilitate preparation of specimens.

3.1.3 The minimum ring inner diameter shall be 60 mm. If soil specimens are to be obtained by extruding and trimming, the inner diameter of the ring shall be at least 10 mm less than the inside of the sample tube. For soils which may break or deform badly during extrusion and trimming, the inside diameter of the ring shall be equal to the diameter of the tube sample.

NOTE — In special cases, diameter may be 50 mm.

3.1.4 The height of the ring shall be not less than 20 mm with a diameter to height ratio of about 3.0 and further the specimen height shall not be less than 10 times the maximum particle size.

3.2 Porous Stones

3.2.1 These stones shall be placed at the top and the bottom of the soil specimen, and shall be of silicon carbide, aluminium oxide or other porous materials not attacked by the soil or soil moisture and not undergoing any

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

electro-chemical reaction with other parts of the equipment.

3.2.2 The porosity of the stones shall be such that free drainage is assured throughout the test, but that no intrusion of soil into the pores of the stones takes place. If necessary, a sheet of Whatman No. 54 filter paper (or other filter paper of comparable permeability) of diameter equal to that of the stone, may be placed between the stone and the soil surface, in order to prevent intrusion.

NOTE — Filter paper shall not be used when stiff clays are being tested since the paper has high compressibility.

3.2.3 The diameter of the top stone shall be 0·2-0·5 mm less than that of the inside diameter of the ring. A fixed ring system may be used, in which case the bottom stone shall be of large enough diameter to support the consolidation ring and its specimen adequately. If a floating ring is used, the bottom stone shall have the same diameter as the top stone.

3.2.4 It is recommended that stones which protrude into the ring during the test be tapered with the large diameter in contact with soil, in order to prevent binding and friction between stone and ring in case of tilting.

3.2.5 The thickness of the stones shall be sufficient to prevent breaking under load. The top stone shall be loaded through a corrosion resistant loading cap of sufficient rigidity to prevent breakage of the stone.

3.2.6 The stone surfaces shall be flat, clean and free of cracks and chips.

3.3 Consolidation Cell — A container within which is placed the consolidation ring containing the specimen between the top and bottom porous stones. The cell shall be capable of being filled with water to a level higher than the top of the upper porous stone, of having an axial, vertical load applied to the top of the specimen and of allowing measurement of the change in height of the specimen on its central axis.

3.4 Dial Gauge—The gauge shall read to an accuracy of at least 0·01 percent of the specimen height, and have a travel of at least 50 percent of the specimen height (*see* IS : 2092-1983*).

3.5 Loading Device

3.5.1 The device shall enable vertical force to be applied axially, in suitable increments, to the test specimen, through a suitable loading yoke. It shall be capable of maintaining specified loads for long periods of time while the specimen is deforming, with a variation of less than ±1 percent of the applied load.

*Specification for plunger type dial gauges (*first revision*).

3.5.2 The force is applied to the loading cap of the specimen centrally, through some form of spherical seating. The applied load is known to an accuracy of at least ± 1 percent.

3.5.3 The loading device shall permit application of a load increment within a period of 2 s, without significant impact.

3.5.4 The device should be located on a firm base, in an environment free of vibrations and other mechanical disturbances, and preferably under constant temperature conditions.

3.6 Jack and Frame — for extruding the soil from sampling tubes.

3.7 Jig — for holding consolidation ring above the sampling tube for direct jacking methods of specimen preparation.

3.8 Trimming Equipment — metal straightedge, thin bladed trimming knife (like spatula), wire saws.

3.9 Equipment for Measuring Initial Height of Test Specimen to an Accuracy of 0·1 mm — vernier reading callipers, micrometer screw gauge or 25 mm travel dial-gauge mounted in comparator.

3.10 Moisture Content Containers, Drying Air-Oven Maintained at 110 ± 5°C Desiccator

3.11 Balances Sensitive to 0·01 g — for weighing the specimen and determining moisture content.

3.12 Timing Device Readable to 1 s

4. PROCEDURE

4.1 Preparation of Test Specimen

4.1.1 Weigh the empty consolidation ring, designated W_1.

4.1.2 If the specimen is to be prepared from a tube sample, a representative sample for testing shall be extruded and cut off, care being taken to ensure that the two plane faces of the resulting soil disc are parallel to each other. The thickness of the disc of soil shall be somewhat greater than the height of the consolidation ring.

If the specimen is to be prepared from a block sample, a disc similar in size to that specified above shall be cut from the block, with two parallel faces. The diameter of the disc shall be at least 10 mm greater than the inside diameter of the consolidation ring. Care shall be taken to ensure that the soil stratum is oriented such that the laboratory test will load the soil in the same direction relative to the stratum as the applied force in the field.

4.1.3 Using the weighed consolidation ring as a template, the edges of the disc obtained in **4.1.2** shall be trimmed carefully until the ring just slides over the soil. The last fraction of soil is pared away by the cutting edge of the ring as it is pushed down slowly and evenly over the sample, with no unnatural voids against the inner face of the ring; this process is best done using a mechanical guide to prevent tilting or horizontal movement of the ring. The top and bottom surfaces shall project above and below the edges of the ring to enable final trimming. An alternate procedure is described in **4.1.4**.

Should an occasional small inclusion interfere with the trimming operation, it shall be removed, and the cavity filled completely with material from the parings. Alternatively, if sufficient sample is available, it would be preferable to eventually extrude and discard the portion of the specimen containing the inclusion from the ring, leaving a specimen free of such disturbed zones. If inclusions are known to exist in a soil sample, a large diameter consolidation ring should be used, in order to minimize the relative effect of the disturbed zones. If excessive inclusions are encountered during trimming, the sample should be discarded. If no alternative exists, the tube sample shall be extruded directly into a consolidation ring of equal diameter.

4.1.4 An alternative procedure for obtaining a specimen from a soil disc as obtained in **4.1.2** is to use the consolidation ring as sampling device. The ring should be gradually inserted into the sample by pressing with hands and carefully removing the material and the ring. This can also be accomplished using a mechanically operated jig.

4.1.5 The soil sample thus obtained according to **4.1.3** or **4.1.4** shall be trimmed flush with the top and bottom edges of the ring. For soft to medium soils, excess soil should be removed using a wire saw, and final trimming may be done with a straight edge if necessary. For stiff soils, a straight edge alone may be used for trimming. Excessive remoulding of the soil surface by the straight edge should be avoided. In the case of very soft soils, special care should be taken so that the specimen may not fall out of, or slide inside the ring during trimming.

4.1.6 A sample of soil similar to that in the ring, taken from the trimmings, shall be used for determining moisture content.

4.1.7 The thickness of the specimen (H_0) shall be measured and it shall be weighed immediately (W_2). Should the nature of the soil make satisfactory thickness determination difficult, the ring height may be assumed as specimen height.

4.2 Assembly of Apparatus

4.2.1 The bottom porous stone shall be centered on the base of the consolidation cell. If over consolidated clay, or soils sensitive to moisture increase (swelling or collapsing soils) are being tested, the stone should be placed dry. When testing softer, normally consolidated clays, the stone should be wet, and it may be covered by a wet filter paper. No filter paper shall be used for the stiffer and moisture sensitive soils.

4.2.2 The ring and specimen shall be placed centrally on the bottom porous stone, and the upper porous stone and then the loading cap shall be placed on top. The top stone shall be placed dry or wet, and with or without filter paper, in accordance with **4.2.1**.

4.2.3 The consolidometer shall be placed in position in the loading device and suitably adjusted. The dial gauge is then clamped into position for recording the relative movement between the base of the consolidation cell and the loading cap. A seating pressure of 0·05 kgf/cm^2 shall be applied to the specimen.

4.2.4 The consolidation cell shall be filled with water, preferably of the same ionic content as the specimen pore water. If this is not possible, distilled water shall be used. The type of water used shall be noted in the data sheet.

4.2.5 The specimen shall then be allowed to reach equilibrium for 24 h.

4.3 Loading

4.3.1 For consolidation testing, it is generally desirable that the applied pressure at any loading stage be double than that at the preceding stage. The test may, therefore, be continued using a loading sequence which would successively apply stress of 0·1, 0·2, 0·4, 0·8, 1·6, 3·2, etc, kgf/cm^2 on the soil specimen.

4.3.2 For each loading increment, after application of load, readings of the dial gauge shall be taken using a time sequence such as 0, 0·25, 1, 2·25, 4, 6·25, 9, 12·25, 16, 20·25, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225, etc, min, up to 24 h or 0, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, 15, 30, 60 min, and 2, 4, 8, 24 h. These time sequences facilitate plotting of thickness or change of thickness of specimen against square root of time or against logarithm of time.

The loading increment shall be left at least until the slope of the characteristic linear secondary compression portion of the thickness versus log time plot is apparent, or until the end of primary consolidation is indicated on a square root of time plot. A period of 24 h will usually be sufficient, but longer times may be required. If a period of 24 h is seen to be sufficient, it is recommended that this commonly used load period be used for all load increments. In every case, the same load increment duration shall be used for all load increments during a consolidation test.

4.3.3 It is desirable that the final pressure be of the order of at least four times the pre-consolidation pressure, and be greater than the maximum effective vertical pressure which will occur *in situ* due to the overburden and the proposed construction.

4.3.4 On completion of the final loading stage, the specimen shall be unloaded by pressure decrements which decrease the load to one-fourth of the last load. Dial gauge readings may be taken as necessary during each stage of unloading. If desired, the time intervals used during the consolidation increments may be adopted; usually it is possible to proceed much more rapidly.

4.3.5 In order to minimize swell during disassembly, the last unloading stage should be to 0·05 kgf/cm² which should remain on the specimen for 24 h. On completion of this decrement, the water shall be siphoned out of the cell and the consolidometer shall be rapidly dismantled after the release of the final load. The specimen, preferably within the ring, shall be wiped free of water, weighed (W_3), and thereafter placed in the oven for drying. If the ring is required for further testing, the specimen may carefully be removed from the ring in order to prevent loss of soil, and then weighed and dried.

4.3.5.1 Following drying, the specimen (plus ring) shall be reweighed (W_4).

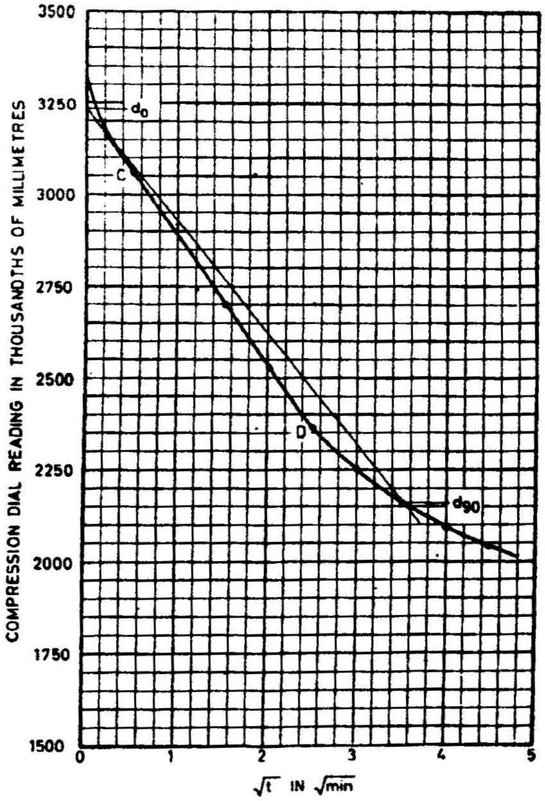
4.3.5.2 The porous stones shall be boiled clean after the test, in order to prevent clay from drying on them and reducing their permeability.

5. RECORD OF OBSERVATIONS

5.1 Specimen Data — The specimen data shall be recorded at the top of the data sheet shown in Appendix A. This includes apart from soil identification, etc, specific gravity of soil particles, the specimen measurements and water content determinations. The specimen preparation procedure and the type of water used shall also be specified.

5.2 Consolidation Data — The data concerning dial readings with time for each pressure increment for both loading and unloading stages shall be recorded on the data sheet shown in Appendix B.

5.2.1 The data obtained after specimen disassembly concerning the final wet weight of the specimen (W_3) and the dry weight (W_4) shall be recorded in space provided in Appendix A.

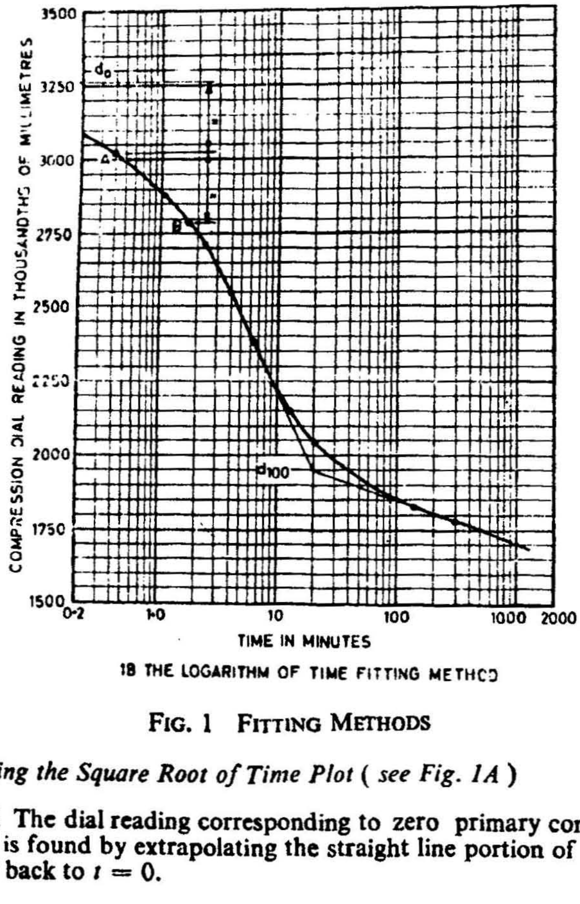


1A THE SQUARE ROOT OF TIME FITTING METHOD

FIG. 1 FITTING METHODS — (*Continued*)

6. CALCULATIONS

6.1 Determination of Coefficient of Consolidation, (c_v) — Plot dial gauge readings versus $\sqrt{t}$ (*see* Fig. 1A) or versus log of time (*see* Fig. 1B) for each load increment and draw smooth curve joining the points. Each curve should be identified by noting down the pressure acting on the specimen during the load increment and the duration of the load increment. The coefficient of consolidation, c_v, determined from the above curves, shall be recorded on the curves as well.



1B THE LOGARITHM OF TIME FITTING METHOD

FIG. 1 FITTING METHODS

6.1.1 *Using the Square Root of Time Plot (see Fig. 1A)*

6.1.1.1 The dial reading corresponding to zero primary consolidation, that is, d_0, is found by extrapolating the straight line portion of the curve, that is, *DC* back to $t = 0$.

6.1.1.2 A straight line is then drawn from d_0 such that the abscissae of this line are 1·15 times the abscissae of the straight line *CD*.

6.1.1.3 The point at which the drawn line intersects the experimentally obtained curve, that is, d_{90}, corresponds to 90 percent primary consolidation.

6.1.1.4 The time required for 90 percent consolidation is read off the curve as t_{90} and recorded in col 9 of Appendix A.

6.1.1.5 The coefficient of consolidation, c_v, for the load increment under consideration may be calculated from the formula:

$$c_v = \frac{0.848 \left(\frac{H_{av}}{2} \right)^2}{t_{90}}$$

where H_{av} is the average specimen thickness for the load increment given in col 10 of Appendix A and c_v has units of (length)^2 per unit time consistent with the units used and should be recorded in col 11 of Appendix A.

6.1.2 *Using the Log of Time Plot* (*see Fig. 1B*)

6.1.2.1 The two straight line 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.

6.1.2.2 In order to find the dial gauge reading corresponding to zero percent primary consolidation, d_0, the readings at two times having a ratio of 1 to 4 are noted on the early part of the curve (*see* points *A* and *B* in Fig. 1B). These points are chosen to be in the range such that the larger of the two should be greater than one-fourth but less than half of the total deformation for the load increment. The dial gauge reading corresponding to zero primary consolidation is determined as the reading at *A* plus the difference in reading between *A* and *B*.

6.1.2.3 The dial gauge reading corresponding to 50 percent primary consolidation is calculated as the average of the readings corresponding to 0 and 100 percent consolidation. The time required for this deformation is read off the curve (t_{50} in Fig. 1B) and recorded in col 9 of Appendix A.

6.1.2.4 The coefficient of consolidation, c_v, may be calculated from the formula:

$$c_v = \frac{0.197 \left(\frac{H_{av}}{2} \right)^2}{t_{50}}$$

and recorded in col 11 of Appendix A.

6.2 Determination of Compressibility

6.2.1 *Coefficient of Compressibility*

6.2.1.1 Transfer the final dial gauge reading for each pressure increment from Appendix B to col 2 of Appendix A, recording it against the total applied pressure which is noted in col 1 of Appendix A.

6.2.1.2 From the dry weight of the specimen, W_s the volume of soil solids, V_s, shall be obtained as

$$V_s = \frac{W_s}{G_s \gamma_w}$$

where

G_s = specific gravity of the solid particles, and

γ_w = unit of water.

6.2.1.3 The equivalent height of soil solids can be determined as

$$H_s = \frac{V_s}{A}$$

where A is area of specimen in cm².

6.2.1.4 From col 2 of Appendix A, determine ΔH for each pressure increment and record it in col 3.

6.2.1.5 The height of specimen at the end of each pressure increment, H, can be determined by subtracting ΔH of a particular increment from H of the specimen prior to application of that increment. This is to be recorded in col 4 of Appendix A.

6.2.1.6 Void ratio, e, is obtained as

$$e = \frac{H}{H_s} - 1$$

and recorded in col 5 of Appendix A.

6.2.1.7 Values of de and d$\bar{\sigma}$ obtained from col 5 and 1 of Appendix A respectively are recorded in col 6 and 7 of Appendix A (de and d$\bar{\sigma}$ being the differences between successive values of e and $\bar{\sigma}$, respectively).

6.2.1.8 The coefficient of compressibility, a_v, with units of inverse of units for stress shall be calculated as

$$a_v = \frac{de}{d\bar{\sigma}}$$

and recorded in col 8 of Appendix A.

6.2.2 *Compression Index, C_c*

6.2.2.1 Plot the void ratio, e versus log $\bar{\sigma}$. The slope of the straight line portion, that is, for the soil in the normally consolidated state, is designated as C_c. This can be directly obtained from the plot or calculated as

$$C_c = \frac{de}{\log \frac{\bar{\sigma}_2}{\bar{\sigma}_1}}$$

where $\bar{\sigma}_2$ and $\bar{\sigma}_1$ are the successive values.

7. PRESENTATION OF RESULTS

7.1 The results of a consolidation test are presented in the form of a set of curves showing the relationship of e versus log $\bar{\sigma}$, a_v versus log $\bar{\sigma}$ and c_v versus log $\bar{\sigma}$. The value of C_c is also reported separately.

APPENDIX A

(*Clauses* 5.1, 5.2.1, 6.1.1.4, 6.1.1.5, 6.1.2.3, 6.1.2.4, to 6.2.1.1, 6.2.1.4 to 6.2.1.8)

CONSOLIDATION TEST : PRESSURE — VOID RATIO DATA

Project________
Sample No.________
Soil Identification________
Specific Gravity________
Specimen Preparation________
Procedure________
Type of Water Used________

Specimen Measurements
Diameter, D = ________ cm
Area, $A = \pi D^2/4$ = ________ cm²
Thickness, H_0 = ________ cm
Wt of ring (W_1) = ________ g
Wt of specimen + ring (W_2) = ________ g
Final wt of specimen (W_3) = g
Dry wt of specimen + ring (W_4) = g
Dry wt of specimen (W_s) = $W_4 - W_1$ = g
Equivalent height of solids

Water Content
Can No. = ________
Wt of can + wet soil = ________ g
Wt of can + dry soil = ________ g
Wt of can = ________ g
Wt of water = ________ g
Wt of dry soil = ________ g

Test No.________
Date________
Tested by________

$$H_s = \frac{W_s}{G_s \gamma_w A}$$

Applied Pressure kfg/cm² $\bar{\sigma}$	Final Dial Reading	Compression ΔH cm	Specimen Height cm	$e = \frac{H}{H_s} - 1$	de	$d\bar{\sigma}$	$a_v = \frac{de}{d\bar{\sigma}}$ cm²/kg	t_{50} or t_{90} min	H_{av} cm	c_v cm²/min	Remarks
1	2	3	4	5	6	7	8	9	10	11	12

APPENDIX B

(*Clauses* 5.2 *and* 6.2.1.1)

CONSOLIDATION TEST : PRESSURE INCREMENT DATA

Project__________ Loading Frame No.__________ Test No.__________

Sample__________ Least Count of Dial Gauge__________ Date__________

Soil Identification__________ Tested by__________

Page No.__________

Pressure Increment			Pressure Increment			Pressure Increment			Pressure Increment		
From____ to____ kgf/cm²			From____ to____ kgf/cm²			From____ to____ kgf/cm²			From____ to____ kgf/cm²		
Date and Time	Elapsed Time (min-h)	Dial Reading	Date and Time	Elapsed Time (min-h)	Dial Reading	Date and Time	Elapsed Time (min-h)	Dial Reading	Date and Time	Elapsed Time (min-h)	Dial Reading
1	2	3	4	5	6	7	8	9	10	11	12

(*Continued from page* 2)

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'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMEDABAD 380001	550 13 48
Peenya Industrial Area, 1st Stage, Bangalore-Tumkur Road, BANGALORE 560058	839 49 55
Commercial-cum-Office Complex, Opp. Dushera Maidan, E-5 Arera Colony, Bittan Market, BHOPAL 462016	72 34 52
62/63, Ganga Nagar, Unit VI, BHUBANESWAR 751001	40 36 27
5th Floor, Kovai Towers, 44 Bala Sundaram Road, COIMBATORE 641018	21 88 35
Plot No. 58, Neelam Bata Road, NIT, FARIDABAD 121001	542 82 61
Savitri Complex, 116 G.T. Road, GHAZIABAD 201001	471 19 98
53/5 Ward No.29, R.G. Barua Road, 5th By-lane, Apurba Sinha Path, GUWAHATI 781003	54 11 37
5-8-56C, L.N. Gupta Marg, Nampally Station Road, HYDERABAD 500001	320 10 84
E-52, Chitranjan Marg, C- Scheme, JAIPUR 302001	37 38 79
117/418 B, Sarvodaya Nagar, KANPUR 208005	21 68 76
Seth Bhawan, 2nd Floor, Behind Leela Cinema, Naval Kishore Road, LUCKNOW 226001	21 89 23
NIT Building, Second Floor, Gokulpat Market, NAGPUR 440010	52 51 71
Mahabir Bhawan, Ist Floor, Ropar Road, NALAGARH 174101	2 14 51
Patliputra Industrial Estate, PATNA 800013	26 28 08
First Floor, Plot Nos. 657-660, Market Yard, Gultekdi, PUNE 411037	426 86 59
'Sahajanand House' 3rd Floor, Bhaktinagar Circle, 80 Feet Road, RAJKOT 360002	37 82 51
T.C. No. 14/1421, University P. O. Palayam, THIRUVANANTHAPURAM 695034	32 21 04

*Sales Office is at 5 Chowringhee Approach, P.O. Princep Street, CALCUTTA 700072	237 10 85
†Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007	309 65 28

Printed at Printograph, New Delh, Ph.: 5726847